INVESTIGATION INTO SOME OF THE ENGINEERING PROPERTIES OF SOILS FOUND IN WEREDA 10 OF BOLE SUB CITY , ADDIS ABABA, ETHIOPIA

BY

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APPROVAL PAGE

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Contents

Acronyms

SBH	Secondary Bore Hole
STP	Secondary Test Pit
PTP	Primary Test Pit
LL	Liquid Limit
PI	Plasticity Index
FS	Free Swell
USCS	Unified Soil Classification System
G_s	Specific Gravity
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
UCS	Unconfined Compressive Strength
AASHTO	American Association of State Highway and Transportation Officials
C	Cohesion force
Φ	Angle of Internal Friction
e_o	Initial Void Ratio
C_c	Compressibility Index
K	Permeability Coefficient
K^2	Coefficient of Determination

List of Tables

List of Figures

Abstract

Soil is the ultimate foundation material which supports the structure. The proper functioning of the structure will, therefore, depend on the engineering properties of the underlying soil.

The objectives of this research is to investigate the engineering properties of soils found in Wereda 10 of Bole Sub-City by conducting different types of laboratory tests, reconnaissance survey of the study area, and collection of secondary data, cross-section profiling and by evaluating relations between UCS and Index properties(P_{200}, LL and PI). This research is useful in providing necessary data or information that can be used in designing civil engineering structures in Wereda 10 of Bole Sub City.

Laboratory tests carried out and collected on disturbed and undisturbed samples revealed that the natural moisture content ranges from 5.47-67.37%, specific gravity of the soils ranges from 2.03-2.87%.

Results of Atterberg limits tests show that soil of Wereda 10 of Bole Sub City have liquid limits ranging from 0-116%, plastic limit ranges from 0-84% and plastic index from non-plastic – 73%.This indicate that soils of the study area has heterogenetic nature and wide range of plasticity. This variation also reflected in their grain size distribution of particles passing 200 sieve that ranges from 10.7% - 99.6%.

The free swell test result indicates that soils of the study area range from non-swelling to 200%, which means the soils in the study area ranges from non-expansive to highly expansive. According to USCS, the soil in the study area classified in to four main types as MH, ML, SM and CH, in their dominance order. Also soil types CL, GM, SC, CL – ML, & SC – SM rarely exist in the study area.

The Compaction test result showed that maximum dry density (MDD) ranges from 1.67 to 1.7 g/cm3 and the optimum moisture content (OMC) ranges 18.5 to 23.4%. The unconfined compressive strength (UCS) test result of the area ranges from 29.94 to 285kN/m2 indicates the soil consistency ranges from soft to very stiff. Moreover, the one dimensional consolidation test result carried in the area showed ranges of initial void ratio (e_o) from 0.7 to 1.52 and compression index (Cc) from 0.09 to 0.336. The permeability test result ranges from 2.8 to 5 (x 10-3) cm/sec, indicating the soil is impervious.

In the effort to correlate the index properties to that of their engineering properties, the UCS of MH soil can be predicted using exponential equation by making use of LL as independent variable which is UCS = $14.692e^{0.0217(LL)}$ with R^2 of 0.5449. However, no clear correlations are observed between UCS and P_{200}/PI. In the other hand, the UCS of CH soil can be predicted using either of exponential or linear equation by making use of P200/LL/PI as independent variable which is UCS = $9.1527e^{0.0315P_{200}}$, UCS = $10^6\ e^{-0.156LL}$, UCS = $821768e^{-0.303PI}$, UCS = 3.3608(P_{200}) – 137.19, UCS = -17.929(LL) + 1183.6, UCS = 34.072(PI)+ 1132.2. Their R^2 are 0.8844, 0.8544, 0.7696, 0.7681, 0.856, and 0.7397 respectively.

Generally, the cross-section profile of the area reveals that soil layers can be explained with the soil profile successions of black cotton (silty clay/clayey silt) as a top layer, silty clay/clayey silt soil layer, sandy silt/Silty sand layer, sandy gravel layer and weathered ignimbrite layers with variable thickness.

CHAPTER ONE

Introduction

1.1 Background and Justification

Engineering properties of soils play a significant role in civil engineering construction works particularly in road constructions, foundations, embankments and dams to mention a few. These made imperative use, the testing of soil, on which a foundation or super structure is going to be laid on. This would determine its geotechnical suitability as a construction material. In recent times, the alarming rate at which lives are being lost due to collapsed buildings and road failures calls for a solution. The solution could be brought by critical geotechnical testing of the engineering soil. Investigation of the underground conditions at a site is prerequisite to the economical design of the sub structure elements. It is also necessary to obtain sufficient information for feasibility and economic studies of the proposed project. Public building officials may require soil data together with the recommendations of the geotechnical consultant prior to issuing a building permit, particularly if there is a chance that the project will endanger the public health or safety or degrade the environment (Bowles, 1996).

Inadequate geotechnical investigations, faulty result interpretations, or failure to present results in a clearly understandable manner may contribute to inappropriate designs; delays in construction schedules, costly construction modifications, and use of substandard borrow material, environmental damage to the site, post construction remedial work, and even failure of a structure and subsequent litigation (Website, http/en.wikedia.org/wiki/Durame, Fitsum, 2013). Therefore, to obtain information on type, characteristics and distributions of a soil, geotechnical investigations should be done on soil and rock underlying (and sometimes adjacent to) a site of proposed structures. In a country like Ethiopia which is developing at high growth rate and which needs many construction works in the future, geotechnical investigation on the engineering property of soil is very essential. Because these data are very important for civil engineers in preliminary design and in designing foundation, pavement, retaining structures, etc. for future construction projects in the country. The study area, 'Woreda 10', which is found in Bole Sub-City, is one of future expansion corridors of the city (Addis Ababa). Many communal residential multi-storey buildings are carried, being carried and will be carried in the future. Therefore, it will be vital to study the engineering properties of soils of this area as no or little specific relevant studies are available.

1.2 Statement of the problem

During the past fifty years Ethiopia has witnessed a dramatic increase in urbanization associated with ever increasing population. The rapid growth of cities, industry, and commerce required myriad building systems, railroads, highways, ports, bridges, airports and runways and towers for communication systems. These building systems require stable and economic foundations. Presently, the construction of high-rise buildings is booming in Addis Ababa. Geotechnical firms are also mushrooming in response to the increasing demand for foundation investigations. Serious failure of buildings and other infrastructures in the city were not occurred yet. However, there is no guarantee that failure of structures will not occur in the future unless detailed understanding of the behavior of geological materials is made. The availability of National Geotechnical Databases is therefore highly required for designers, policy makers and researchers, for the healthy development of the country and the capital city in particular. Although many geotechnical investigations have been carried out in the city, starting from the past three decades, data is hardly available in a manageable form. As a result, researches in the area of geotechnical engineering, foundation engineering and earthquake engineering are difficult to undertake. It should be understood that these specializations are expected to contribute a lot for the healthy development of the city. These can ensure the safety and stability of infrastructures and hence the well-being of the citizen at large. However, there is a need of high quality geotechnical database. Thus, keeping these facts in mind the present study was conceived with an objective to undertake a comparative assessment of the engineering properties of soils in Woreda 10 of Bole sub city through the development of a geotechnical database from previous borehole logs and laboratory test results data and primary pit data and laboratory tests. Accordingly, in this research efforts were made to characterize the engineering properties of soil in the study area.

1.3 Objective of the Study

1.3.1 General Objective

This research aims to characterize the engineering properties of soil in Woreda-10 of Bole Sub-City, Addis Ababa.

1.3.2 Specific Objective

In this research the following specific objective will be addressed;

- To review the previous relevant works in the area
- To conduct field soil survey, measurements and sampling.
- To do selected laboratory testing relevant to soil characterization
- To characterize the study area soil.
- To see if there is relationship/correlation between index properties (P_{200}, LL, PI) and UCS of the area soil.

- To evaluate the engineering properties of soil in the study area.

1.4 Scope and Limitation of the Study

Though the study covers one of the big Woreda in one of the big Sub cities of the capital, Addis Ababa, the scope of the study is limited to identifying the engineering properties of soils in the area. The database that is presented has been compiled about the past 8 years. In all cases, the data were obtained from private and governmental laboratories dedicated to geotechnical engineering practice and construction project owners. This imposes an error due to changes in personnel and testing procedures over time. However, despite all these difficulties and limitations, all efforts were made to conduct this study in a systematic manner with actual data and information gathered from both primary and secondary sources. The data was collected from AASHDE 40/60 projects at bole Ayat site & Beshale site. Data of AASHDE 20/80 projects from best consulting Engineers plc. and also from different Soil investigation firms as JEROCCIA Geotechnical Services and Engineering plc., and Eniy real estate. A total of 66 boreholes and 10 test pits from these secondary sources and 3 primary test pits have been considered for this research work.

1.5 Structure of the Thesis

This thesis work is structured in six chapters. The first chapter deals with an introduction part in which problem background, objective of the study, scope and limitation of the research are addressed.

Second chapter which presents the brief literature review part of the thesis. In the chapter soil formation and deposit regarding to parent material, topography and drainage and climate factors are reviewed. General soil types depending on soil particle size and shape and also mineralogical composition, parameters of soil properties (physical, index and engineering) are addressed too.

The third chapter deals with the description of the study area. This chapter tries to discuss the geology, soil characteristics, topography, drainage conditions and climatic conditions of the study area.

The fourth chapter tries to present the methodology of the research work. In this chapter secondary, primary data sources of engineering and index properties of the soil are explained.

In the fifth chapter result discussions of test results is presented. In Chapter six conclusions from test results are drawn and finally recommendation is presented.

CHAPTER TWO

Literature Review

2.1 General

The word 'soil' has different meanings for different professions. From the point of view of an engineer, soil includes all earth materials, organic and inorganic, occurring in the zone overlying the rock crust.
The behavior of a structure depends upon the properties of the soil materials on which the structure rests. The properties of soil materials depend upon the properties of the parent rocks (Murthy, 1990).
The variety of soil materials encountered in engineering problems is almost limitless, ranging from hard, dense, large pieces of rock through to gravel, sand, silt, and clay to organic deposits of soft compressible peat. To compound the complexity, all of these materials may occur over a range of densities and water contents. At any given site, a number of different soil types may be present, and the composition may vary over intervals of a little as a few inches (James, 1976).
Material characteristics can be determined from disturbed samples of the soil, i.e. samples having the same particle size distribution as the in-situ soil but in which the in-situ structure has not been preserved. The principal material characteristics are particle size distribution (or grading) and plasticity, from which the soil name can be deduced. (Craig's, 2004)

2.2 Soil formation and soil deposit

It has long been appreciated that the engineering classification of soils is greatly facilitated by taking into account the soil-forming processes by which nature has created the various types of soil conditions. Similar combinations of soil-forming processes in different parts of the world have been found to lead to materials of similar index properties and similar engineering characteristics (Taylor, 1990).The main factors affecting the formations of soil are: Parent materials i.e. Geology of the area, topography and drainage, climate and vegetation cover. (Debebe, 2011 as sited in Yimam Mohammed, 2016)

2.2.1 Parent material

The properties of the soil materials depend upon the properties of the rocks from which they are derived. (Murthy, 1990).
Soils are formed by the process of weathering of the parent rock. The weathering of the rocks might be by mechanical disintegration, and/or chemical decomposition. The mechanical disintegration of rocks results no chemical alteration of the parent rock simply it is breaking away of parent material into small pieces. On the other hand Chemical decomposition involves some chemical reactions like hydration, oxidation and

carbonation resulting in altered chemical composition of the original parent rock in addition to its size reduction. These two weathering processes may go side by side to facilitate formation of soil from the parent material/rock.

2.2.2 Topography and drainage

Topography is responsible for the drainage behavior of an area. The weathered rock materials are transported to different places in a prevailing drainage pattern. Its control over soil properties is particularly strong in tropical environment reflecting the importance of lateral movement of water and soil materials (Taylor, 1990). Topography controls the rate of weathering by partly determining the amount of available water and the rate at which it moves through the zone of weathering. In addition to this, it also controls the effective age of the profile by controlling the rate of erosion of weathered material from the surface. Thus, deeper residual profiles will generally be found in valleys and gentle slopes rather than on high ground or steep slopes (Blight, 1997).

According to Blight (1997), studies made on formation of residual soils from basic igneous rocks reveal that topography and drainage plays a significant role. Topography may also control the type of clay minerals produced. According to the study made upon samples taken from three different sites, samples taken from a site high upon a slope with good run off were shown kaolinite and vermiculite are the dominating clay minerals. A gentle sloped sites indicated chlorite, vermiculite, montmorillonite and kaolinite in weathering sequence. Samples taken from a flat site with impeded drainage has shown montmorillonite as the predominant mineral. This study indicated that good internal drainage and high rainfall are favorable to the development of kaolinite whilst flatter slopes and poor drainage favor the formation of montmorillonite. All these points indicate the significance of studying/analyzing the nature of a given soil relative to the specific conditions under which it is formed.

2.2.3 Climate

Climate is one factor that affects the weathering and formation of soil from the parent material. The dominant factors of climate include temperature and rainfall.

The seasonal heating and cooling of temperature results in differential heating effect of the parent rock. This by effect leads to rock disintegration in to reduced sizes. And also temperature induces imperative effect on the chemical weathering of rocks.

Regarding to rainfall, its amount and distribution are crucial in soil formation. This factor is source of runoff which could be the agent for erosion and transporting weathered rock product (soil) to a different location.

The amount and distribution of precipitation affects the availability of moisture and the relative humidity of the soil atmosphere; it influences the concentration or chemical activities of solutions in the system (Gilloth, 1995).

2.3 General type of soils

According to their grain size, soil particles are classified as cobbles, gravel, sand, silt and clay. Grains having diameters in the range of 4.75mm to 76.2mm are called gravel. If the grains are visible to the naked eye, but are less than about 4.75mm in size the soil is described as sand. The lower limit of visibility of grains for the naked eyes is about 0.075mm. Soil grains ranging from 0.075mm to 0.002mm are termed as silt and those that are finer than 0.002mm as clay. This classification is purely based on size which does not indicate the properties of fine grained materials (Murthy, 1990).

Residual and Transported Soils

On the basis of origin of their constituents, soils can be divided into two large groups:

1. Residual soils, and
2. Transported soils.

Residual soils are those that remain at the place of their formation as a result of weathering of parent rocks. The depth of residual soils depends primarily on climatic conditions and the time of exposure. In some areas, this depth might be considerable. In temperate zones residual soils are commonly stiff and stable. An important characteristic of residual soil is that the sizes of grains are indefinite. For example, when a residual sample is sieved, the amount passing any given sieve size depends greatly on the time and energy expended in shaking, because of the partially disintegrated condition.

Transported soils are soils that are found at locations far removed from their place of formation. The transporting agencies of such soils are glaciers, wind and water. The soils are named according to the mode of transportation. Alluvial soils are those that have been transported by running water. The soils that have been deposited in quiet lakes, are lacustrine soils. Marine soils are those deposited in sea water. The soils transported and deposited by wind are aeolian soils. Those deposited primarily through the action of gravitational force, as in landslides, are colluvial soils. Glacial soils are those deposited by glaciers. Many of these transported soils are loose and soft to a depth of several hundred feet. Therefore, difficulties with foundations and other types of construction are generally associated with transported soils. (Murthy, 1990).

2.4 Soil particle size and shape

The size of particles may range from gravel to the finest size possible. Their characteristics vary with the size. Soil particles coarser than 0.075 mm are visible to the naked eye or may be examined by means of a hand lens. They constitute the coarser fractions of the soils. The coarser fractions of soils consist of gravel and sand. The individual particles of gravel, which are fragments of rock, are composed of one or more minerals, whereas sand grains contain mostly one mineral which is usually quartz. The individual grains of gravel and sand may be angular, sub angular, sub-rounded, rounded or well-rounded. Gravel may contain grains which may be flat. Some sands contain a fairly high percentage of mica flakes that give them the property of elasticity. Silt and clay constitute the finer fractions of the soil. Any one grain of this fraction generally consists of only one mineral. The particles may be angular, flake-shaped or sometimes needle-like (Murthy, 1990).

2.5 Mineralogy of clay

Minerals are crystalline materials and make up the solids constituent of a soil. The mineral particles of fine grained soils are platy. Minerals are classified according to chemical composition and structure. Most minerals of interest to geotechnical engineers are composed of oxygen and silicon, two of the most abundant elements on earth. Silicates are a group of minerals with a structural unit called the silica tetrahedron. Silicate minerals are formed by addition of cat ion and interactions of tetrahedrons. Silica tetrahedrons combine to form sheets, called silicate sheets, which are thin layers of silica tetrahedrons in which three oxygen ions are shared between adjacent tetrahedrons. Silicate sheets may contain other structural units such as alumina sheets. Alumina sheets are formed by combination of alumina minerals, which consists of an aluminum ion surrounded by six oxygen or hydroxyl atoms in an octahedron.

The main groups of crystalline materials that make up clays are the minerals: Kaolinite, illite, and montmorillonite.

2.5.1 Kaolinite

Kaolinite has a structure that consists of one silica sheet and one alumina sheet bonded together into a layer about 0.72nm thick and stacked repeatedly. The layers are held together by hydrogen bonds.

The structural units join together by hydrogen bond, which develops between the oxygen of silica sheet and hydroxyls of alumina sheet. As the bond is fairly strong, the mineral is stable. Moreover, water cannot easily enter between the structural units and cause expansion.

2.5.2 Illite
Illite consists of repeated layers of one alumina sheet sandwiched by two silicate sheets. The layers, each of thickness 0.96nm, are held together by potassium ions. Illite swells less than montmorillonite. However, swelling is more than in kaolinite.

2.5.3 Montmorillonite
Montmorillonite has a structure similar to illite, but the layers are held together by weak van der Waals forces and exchangeable ions. Water can easily enter the bond and separate the layers in montmorillonite, causing swelling. Montmorillonite is often called swelling or expansive clay.

2.6 Laboratory Tests

A wide variety of laboratory tests can be performed on soils to measure a wide variety of soil properties. Some soil properties are intrinsic to the composition of the soil matrix and are not affected by sample disturbance, while other properties depend on the structure of the soil as well as its composition, and can only be effectively tested on relatively undisturbed samples. Some soil tests measure direct properties of the soil, while others measure "index properties" which provide useful information about the soil without directly measuring the property desired.

2.6.1 Index Properties

The main index properties of coarse grained soils are particle size and relative density. For fine grained soils, the main index properties are Atterberg limits and consistency (Arora, 2004).

2.6.1.1 Natural moisture content
The water content of a soil is an important parameter that controls its behavior. It is quantitative measure of the wetness of a soil mass. The water content of a soil can be determined to a high degree of precision, as it involves only mass which can be determined more accurately than volumes (Arora, 2004).

For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine grained soil largely depends on its water content. The characteristics of a soil, especially a fine-grained soil, change to a marked degree with a variation of its water content (Das, 2007).

2.6.1.2 Specific gravity

Specific gravity of soil is the ratio of weight of a given volume of soil particles in air at a stated temperature to the weight of an equal volume of distilled water at a stated temperature. The specific gravity of a soil is often used in relating a weight of soil to its volume. The specific gravity of soil is used in calculating phase relationships of soils (that is the relative volumes of solids to water and air in a given volume of soil) (Krishna, 2002).

Generally, geotechnical engineers need the soil's specific gravity to perform additional testing of that soil. A soil's specific gravity largely depends on the density of the minerals making up the individual soil particles. However, as a general guide, some typical values for specific soil types are as follows (Das, 2007).

- ✓ The specific gravity of the solid substance of most inorganic soils varies between 2.60 and 2.90.
- ✓ Sand particles composed of quartz have a specific gravity ranging from 2.64 to 2.66.
- ✓ Inorganic clays generally range from 2.70 to 2.90.

Soils with large amounts of organic matter or porous particles (such as diatomaceous earth) have specific gravities below 2.60. Some range as low as 2.00.

2.6.1.3 Grain size distribution

In any soil mass, the sizes of the grains vary greatly. To classify a soil property grain size distribution is required. The grain size distribution of coarse grained soil is generally determined by means of sieve analysis. For a fine grained soil, the grain size distribution can be obtained by means of hydrometer analysis (Murthy, 2003).

2.6.1.4 Atterberg Limits

Atterberg Limits are defined as water contents at certain limiting or critical stages in soil behavior. Albert Atterberg (1911), a Swedish agricultural engineer, described a suite of tests that might be performed to determine the water contents at which the character of the mechanical behavior of a clay went through various transitions (Wood, 1990). It defines the boundaries of several states of consistency for plastic soils. The boundaries are defined by the amount of water a soil needs to be at one of those boundaries. The boundaries are called the plastic limit and the liquid limit, and the difference between them is called the plasticity index. The shrinkage limit is also a part of the Atterberg limits (Arora et al, 2007). They are used in classification of fine grained soils, and they are useful because they correlate with the engineering properties and engineering behavior of fine-grained soils (D.H., et al., 1981).

2.6.1.5 Free swell

Both the amount of swelling and the magnitude of swelling pressure are known to be dependent on the clay minerals, the soil mineralogy and structure, fabric and several physic-chemical aspects of the soil. Among clay minerals Montmorillonite influences the magnitude of swelling maximally than Illites and Kaolinites (Das, 2007).

The free swell test is one of the most commonly used simple tests in the field of geotechnical engineering for getting an estimate of soil swelling potential and to identify whether it is expansive or not. Free swell also termed as free swell index. It is the increase in volume of soil without any external constraint when subjected to submergence in water.

Expansive Soils	>100% Free Swell
Marginal	50-100% Free Swell
Non expansive soil	<50% Free Swell

2.6.2 Engineering properties

Engineering properties of soil includes;

- Shear Strength of soil
- Compressibility of soil
- Permeability of soil

2.6.2.1 Shear strength property

The shear strength of a soil is its maximum resistance to shear stresses just before the failure. It is the principal engineering property which controls the stability of a soil mass under loads. It governs the bearing capacity of soils, the stability of slopes in soils, the earth pressure against retaining structure and many other problem. All the problem of soils engineering are related in one way or the other with the shear strength of the soil (Arora, 2004.).

The most common laboratory methods employed to obtain shear strength parameters are direct shear test, unconfined compression test and triaxial compression test. For this thesis UCS test are conducted.

Unconfined compression test is one of the simplest and quickest test used for the determination of shear strength of cohesive soils (Murthy, 1990).

The consistency of clay soils and other cohesive soils is usually described as very soft, soft, medium, stiff, very stiff or hard. The most direct quantitative measure of consistency is the load per unit area at which unconfined cylindrical samples of the soil fails in compression test. This quantity is known as the unconfined compressive strength of the soil (Terzaghi, 1996).

Table 2.1 Consistency and unconfined compression strength of clay soils (Braja, 2008)

Consistency	q_u (kN/m^2)
Very soft	0–24
Soft	24–48
Medium	48–96
Stiff	96–192
Very stiff	192–383
Hard	>383

2.6.2.2 Compressibility

A stress increase caused by the construction of foundations or other loads compresses soil layers. The compression is caused by deformation of soil particles, relocations of soil particles, and expulsion of water or air from the void spaces. (Das, 2007). Compaction and consolidation are compressibility properties of soil.

2.6.2.2.1 Compaction

Compaction is a process of packing the soil particles by reducing the air voids in the soil through mechanical means. Soils have to be compacted to a dense state to improve their engineering properties like shear strength and therefore bearing capacity, stiffness and reduce settlement, compressibility and permeability.

A particular amount of water, which causes maximum lubrication, without becoming excess to cause hindrance is called optimum moisture content (OMC) and at this stage the soil would be compacted at a density called maximum dry density (MDD) (James, 1976).

The laboratory test generally used to obtain the maximum dry unit weight of compaction and the optimum moisture content is called the Proctor compaction test (Proctor, 1933).

2.6.2.2.2 One dimensional consolidation

consolidation is the gradual reduction in volume of a fully saturated soil of low permeability due to drainage of some of the pore water, the process continuing until the excess pore water pressure set up by an increase in total stress has completely dissipated; the simplest case is that of one-dimensional consolidation, in which a condition of zero lateral strain is implicit. The process of swelling, the reverse of consolidation, is the gradual increase in volume of a soil under negative excess pore water pressure. (Craig's, 2004).

Determination of consolidation property of a soil is vital in estimating settlement conditions of soil on which a structure is laid on. This can be achieved by having a clue of the parameters useful in the computation of settlement of soil layer. These properties include index of compressibility and initial void ratio.

Consolidation test also called Odometer test, is a measurement of how soils compress when saturated with water and exposed to varying amounts of load.

Pre-consolidation stress is the maximum vertical effective stress that a soil was subjected to in the past and swelling pressure is defined as the vertical pressures require preventing the volume change of laterally confined sample when it is allowed to take in water (Teferra, et al., 1999).

2.6.2.3 Permeability property

A soil material is permeable if it contains continuous voids. Permeability of a soil is the rate at which water flows through it under action of hydraulic gradient. The passage of moisture through the inter-spaces or pores of the soil is called percolation. Soils having porous enough for percolation to occur are termed 'pervious' or 'permeable', while those which don't permit the passage of water are termed 'impervious' or impermeable'. The rate of flow is directly proportional to the head of water.

Permeability is a very important engineering property of soils. Knowledge of permeability is very essential in a number of soil engineering problems, such as settlement of buildings, yield of wells, seepage through and below the earth structures. (Murty, 2004).

According to United States Be of Reclamation (USBR) Soils having the coefficient of permeability greater than 10^{-3} mm/sec are classified as pervious and those with a value less than 10^{-5} mm/sec as impervious. The soil with coefficient of permeability between 10^{-5} to 10^{-3} mm/sec are designated as semi pervious. (Arora, 2004).

Permeability of a soil can be determined by laboratory test using Constant head permeameter or Falling head permeameter. For this research constant head method is carried.

2.7 Soil Classification

Soil classification is the arrangement of soils into different groups such that the soils in a particular group have similar behavior. It is the sort of labeling of soils with different labels.

As there is a wide varieties of soils covering the earth, it is desirable to systemize or classify the soils into broad groups of similar behavior (Arora, 2004.).

Although, many soil classification systems are present in the world, currently, two more elaborate classification systems are commonly used by soils engineers. Both systems take into consideration the Particle-size distribution and Atterberg limits. They are the American Association of State Highway and Transportation Officials (AASHTO) classification system and the Unified Soil Classification System. The scope of AASHTO classification system is limited to identifying appropriate road subgrade material but the USCS has wide range of uses. Therefore, in this thesis the unified soil classification system (USCS) is followed.

2.7.1 Unified Soil Classification System

The system is most popular for use in all types of engineering problems involving soils. This system classifies soils into two broad categories:

- Coarse-grained soils that are gravelly and sandy in nature with less than 50% passing through the No.200 sieve. The group symbols start with a prefix of G or S. G stands for gravel or gravelly soil, and S for sand or sandy soil.
- Fine-grained soils are with 50% or more passing through the No.200 sieve. The group symbols start with prefixes of M, which stands for inorganic silt, C for inorganic clay, or O for organic silts and clays. The symbol Pt is used for peat, muck, and other highly organic soils (Das, 1997).

2.8 Correlation between Index properties and UCS

Experimentation is very important to determine the engineering properties of soils in Geotechnical Engineering. Special expertise and care are required to perform these tests. The unconfined compression test is one of them. Thus, there is a need to develop models to quickly predict the unconfined compression test of soils.

2.9 Review of previous research works

Investigation of soils is very important in providing necessary data or information that can be used in designing civil engineering structures. Many investigators have studied soils of Ethiopia. Few relevant studies are well reviewed as follows:

- Morin and Perry (1971) studied the origin and mineralogical composition of Ethiopian red clay soils. According to their study Ethiopian red clay soils are principally residual, derived from the weathering of volcanic rocks. The parent rock for black and red clays in Ethiopia is mainly olivine basalt, basalt and trachyte. Ethiopian red clay soils have developed where rain fall is plentiful and drainage is good, and contain Kaolinite and Halloysite as the principal clay minerals, but Montmorillonite is also frequently present in significant amounts. The red color of the Ethiopian soils indicates the presence of iron.

- Hailemariam (1992) has studied about investigation into shear strength characteristics of red clay soils of Addis Ababa. Based on experimental results of index property test soil under investigation are not expansive and no significant variations in the investigated depths as well as in different pits were found. The comparison of Addis Ababa red clay soil and lateritic soils of West Africa shows that the red clay soils investigated are not lateritic.

- Samuel (1989) has studied about investigation in to some of engineering properties of Addis Ababa red clay soils. Based on experimental results from 13 samples around Kolfe, Rufael and Semen Gebeya areas he found out the depth of red clay soil in Addis Ababa ranges from few centimeters to about 10 meters. In the area covered by the study, however, the thickness of the soil is found to be one and half meter in Semen Gebeya and Rufael areas and more than 3m in Kolfe area and finally index property test result indicates the soil is not potentially expansive.

- Ayenew (2004) has studied about investigation into shear strength characteristics of expansive soil of Ethiopia. Based on experimental results the shear strength of expansive soil ranges from 30-150kPa in cohesion and 3-25 degree in angle of internal friction in UU test on unsaturated soil. For saturated soil sample in UU test the cohesion ranges from 55-94kPa. There is a decrease in strength in saturated samples, which shows that the degree of saturation and the suction pressure can have major influence on the shear strength of expansive soil.

- Mesfin (2004) has studied about investigation on index properties of expansive soils of Ethiopia. Based on experimental results from 125 samples shows high clay content, high to extremely high plasticity ranges. From the test result, the expansive soil of Ethiopia is classified as to extremely high swelling potential. Hence, these soils are unsuitable as construction material and should be considered as problematic foundation soils.

- Usama Khalid1 etal, made an attempt to develop correlations to predict the unconfined compressive strength from index properties of soils, which are easier and quicker to determine. Samples were collected from different areas of Pakistan. All the basic tests and unconfined compression test were performed on soil samples as per ASTM standards. According to USCS soil samples were classified as CL, ML, CH and CL-ML. The unconfined compression strength of these soil samples was in the range of 16-495 KN/m2. Finally, relationships were drawn between unconfined compressive strength and index properties of soil. Best possible prediction models were developed using a statistical approach. Developed models predicted the unconfined compressive strength of soil with very less deviation from experimental results. They concluded that unconfined compressive strength can be best predicted using moisture content and dry unit weight. They also developed a multi linear regression model to predict the unconfined compressive strength with percentage error ±9. 5 %. They also developed a curve for quick and easy prediction of unconfined compressive strength of soils.

- Anurag Sarkar, Joyanta Maity, etal in their work (Correlation of Different Physical Properties of Cohesive Soil) has made an effort to develop correlation between clay % and PI with Cc, UCS and un-drained shear strength of cohesive soil, alluvial. In the study, laboratory test results and borehole logs from many parts of Kolkata and Rajarhat-New town area, provided by various private companies have been considered. The available collected data of boreholes from Kolkata and New Town area gave all the parameters required to make the equations and their graphical representation. In the study the correlation showed acceptable results when compared with results generated by laboratory test other than data used for the analysis.

Accordingly, this thesis is intended to add the relevant knowledge base about the soil engineering properties and some prediction models of soil in the study area.

CHAPTER THREE

Description of the study area

3.1 General

The formation of the different types of soils depends on the prevailing environmental factors of an area. The climatic conditions, the geologic and physiographic setup of an area have an impact on the formation of soils. Climatic influence is more significant in Ethiopian soil development than petrology of the parent rock (Morin and Parry, 1971).

This chapter deals with the description of geologic, topographic and drainage, and climate conditions which influenced the formation of soils in the study area. This section also includes description of the soil distribution in the study area and its surrounding.

3.2 Location

The study area is located in the Bole sub-city of Addis Ababa, capital city of Ethiopia. It is administratively known as Woreda 10 of Bole sub-city. It is located 37P zone between 483608E, 489610E and 990769N, 997475N geographic coordinates in UTM and is situated at the western margin of the Main Ethiopian Rift with an aerial coverage of about 27.52 km2 in the Eastern part of Addis Ababa city. Location map of the study area is presented in Figure 3.2.

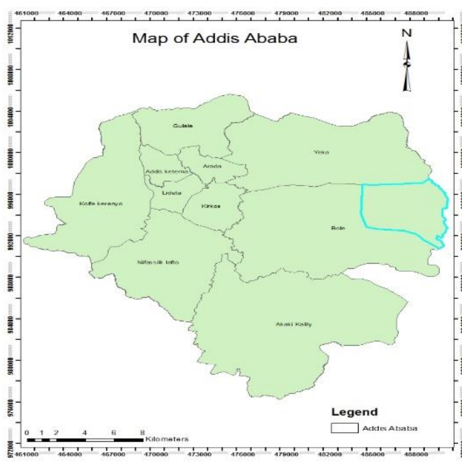

Fig 3.1 Addis Ababa sub-city map

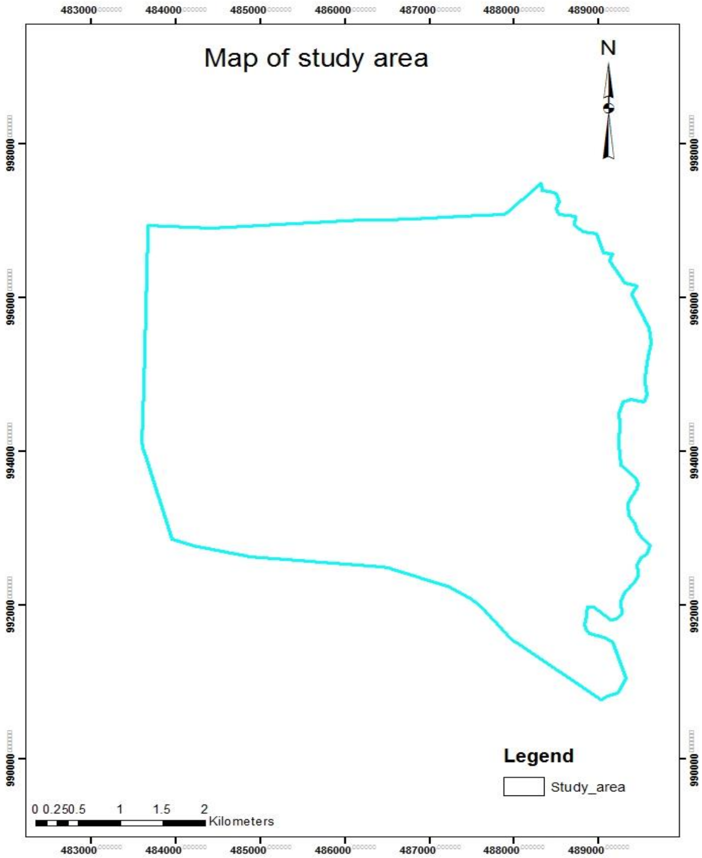

Fig. 3.2 Map of the study area (Wereda 10 of Bole sub city)

3.3 Geology

Addis Ababa city is situated in the western margin of the Main Ethiopian Rift and represents a transition zone between the Ethiopian Plateau and the rift with poorly defined escarpment (Kazmin, 1979).

The general geology of Addis Ababa has been studied by several authors both locally and regionally. The area is covered by different volcanic rocks with both acidic and basic compositions and overlain by fluvial and residual soils varying in thickness from a few cm to about several meters in which black cotton soil is the predominant type (Morton, 1979).The geology of Addis Ababa compiled by Haile Sellasie Girmay and Getaneh Assefa (1989) redefine the litho-stratigraphic units and modified the existing stratigraphic sequence.

The suggested Miocene-Pleistocene volcanic succession ranging from older plateau volcanic to younger rift Volcanics. The rock units are described below according to their stratigraphic order from bottom to top are: Alajibasalts, Intotosilicics, Wachecha Trachyte, Addis Ababa basalts, Nazaret group (Addis Ababa Ignimbrite), and Akaki (Bofa) basalts.

Two of these are found in the study area as could be seen in the fig 3.3. These are Addis Ababa basalts and Nazaret group (Addis Ababa Ignimbrite). Mostly the Addis Ababa Ignimbrite which is tall deposit and poorly welded pyroclastic dominates most of the woreda area. The other geological formation, Addis Ababa basalt which is alkaline & olivine lava flows is limited narrowly to the North West and South West boundary areas of the study area. These geological formation are briefly discussed in the following sections.

3.3.1 *Addis Ababa Basalt*

This unit, which is mainly present in the central part of the town, is underlain by the Intoto silicics and overlain by Lower welded Tuff of the Nazaret group. The maximum thickness exceeding 130 m was found at ketchene stream. Olivine porphyritic basalts outcrop in the central part of the town that includes Mercato, Teklehaymanote and Sidist Kilo. The distribution of plagioclase porphyritic basalt is almost the same as that of the olivine prophyritic basalt. It outcrops in an area, which includes Sidist Kilo, General Winget School and French Embassy. The Lower Welded Tuff overlies both types of basalt nearby the Building College, the Kolfe Police School, the Kokobe Tseba School and Yeka Mariam Church (Haile Sellasie Girmay and Getaneh Assefa, 1989).

3.3.2 *Nazareth Group (Addis Ababa Ignimbrite)*

The lithological units identified in this group are lower welded tuff, aphanitic basalt and upper welded tuff. The group is underlain by Addis Ababa basalt and overlain by Bofa basalts. The rocks outcrop mainly south of Filwoha fault and extended towards Nazareth (Haile Sellasie Girmay and Getaneh Assefa, 1989 as cited in Zeleke Tadesse, 2013).

Lower welded tuff outcrops as small discontinuous body in Filwoha, western parts of Addis Ababa and Sululta. Generally, it is overlain by the aphanitic basalt and underlain by the olivine and plagioclase porphyritic basalt. The age of this unit overlaps with the period of the activity of wechecha trachyte volcanoes (Haile Sellasie Girmay and Getaneh Assefa, 1989).

Aphanitic basalt covers the southern part of the city, especially the area of Bole International Airport and Lideta Old Airfield. The rock body shows vertical curved columnar jointing together with sub-horizonal sheet jointing. Along the course of Akaki River large amygdales of calcite occur in this basalt. Kaolinite lenses are present at the contact with the younger ignimbrite (Haile Sellasie Girmay and Getaneh Assefa, 1989).

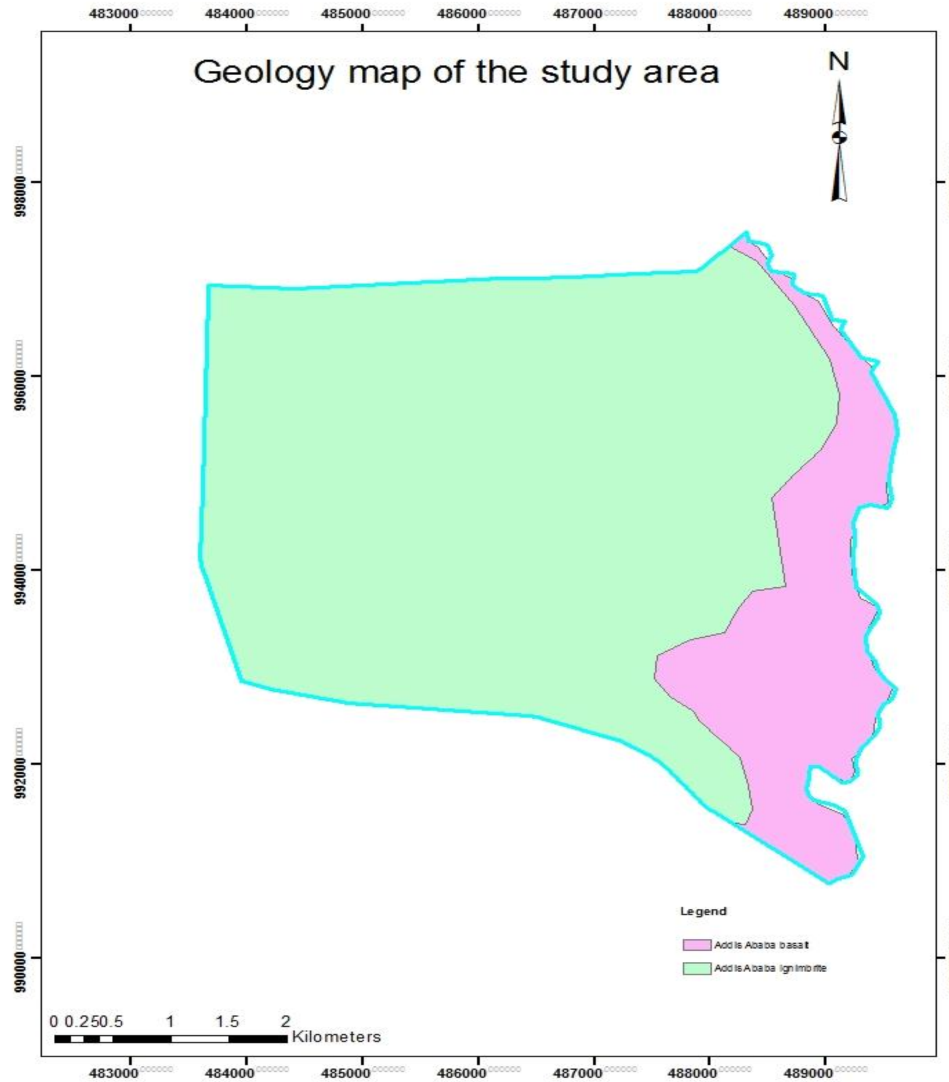

Fig. 3.3 Geological map of the study area

Upper welded tuff outcrops all over the southern parts of the city including Bole, Nefas Silk and Railway Station; nevertheless it is also present in the central and northern part of the city. It is gray colored, vertically and horizontally jointed and composed of sanidine, anortoclase, rebekite, quartz, pumice and unidentified volcanic fragments (Haile Sellasie Girmay and Getaneh Assefa, 1989 as cited in Zeleke Tadesse, 2013). The welded tuff is underlain by aphanitic basalt and overlain by young olivine basalts.

3.4 Topography and drainage conditions

Topographic relief has an important role in soil formation. For a deep residual soil to develop, the rate at which weathering advances into the earth's crust must exceed the rate of removal of the products of weathering by erosion. Topography controls the rate of weathering by partly determining the amount of available water and the rate at which it moves through the zone of weathering. In addition to this, it also controls the effective age of the profile by controlling the rate of erosion of weathered material from the surface. Thus, deeper residual profiles will generally be found in valleys and gentle slopes rather than on high ground or steep slopes. (Blight, 1997 as cited in Hana Tibebu, 2008).

According to Blight (1997), studies made on formation of residual soils from basic igneous rocks reveal that topography and drainage plays a significant role. Topography may also control the type of clay minerals produced. According to the study made upon samples taken from three different sites, samples taken from a site high upon a slope with good run off were shown kaolinite and vermiculite are the dominating clay minerals. A gentle sloped sites indicated chlorite, vermiculite, montmorillonite and kaolinite in weathering sequence. Samples taken from a flat site with impeded drainage has shown montmorillonite as the predominant mineral. This study indicated that good internal drainage and high rainfall are favorable to the development of kaolinite whilst flatter slopes and poor drainage favor the formation of montmorillonite. All these points indicate the significance of studying/analyzing the nature of a given soil relative to the specific conditions under which it is formed.

Addis Ababa is located on the shoulder of the Western Main Ethiopian Rift Escarpment. The morphology is a direct reflection of the different volcanic stratigraphic successions, tectonic activities and the action of erosion between successive lava flows. (Tamiru Alemayehu et al., 2006). The city was founded at the southern flank of Intoto ridge (3199m a.s.l.) and expanded in all directions. This ridge marks the northern boundary of the city following the east-west trending major fault (Ambo-Kassam fault).

Prominent volcanic features surrounding the city are Mt. Wochacha in the west (3385m a.s.l.), Mt. Furi (2839m a.s.l.) in the southwest and Mt. Yerer (3100 a.s.l.) in the southeast. They are characterized by rugged landscapes and steeper slopes. The general inclination of the slope becomes lower towards the southern part of the city. (Tamiru Alemayehu et al., 2006).

The center of the city lies on an undulating topography with some flat land areas. The topography is undulating and form plateau in the northern, western and southwestern parts of the city, while gentle morphology and flat land areas characterize the southern and southeastern parts of the city. Moreover, it is not uncommon to see sharp changes in the inclination of the slope and some flat land areas in different parts of the city.

In the study area, the Akaki River basin is the main river basin which divided the city into two sub basins- the Big Akaki River (Eastern) sub basin and the Little Akaki River (Western) sub basin. The drainage pattern is governed by the geology and physiographic set up of the area. (Tamiru Alemayehu et al., 2006).

The topography of the study areas favors the development of heterogeneous soil profiles by the decomposition of rocks on which it lies. Thus, residual soils are commonly seen in most parts of the city with varying thickness. On the other hand, due to intensive erosional activities there is poor soil development (shallow soil profile) or patchy occurrences on most parts of the slope. The dominant type of soil in the southern parts of the city, where surface water is poorly drained, is expansive clay soil. Similar waterlogged areas are found in the central parts of the city around Filowha, in the eastern parts of the city around Lamberet and in other different parts with small aerial extent contributing to the development of expansive soils.

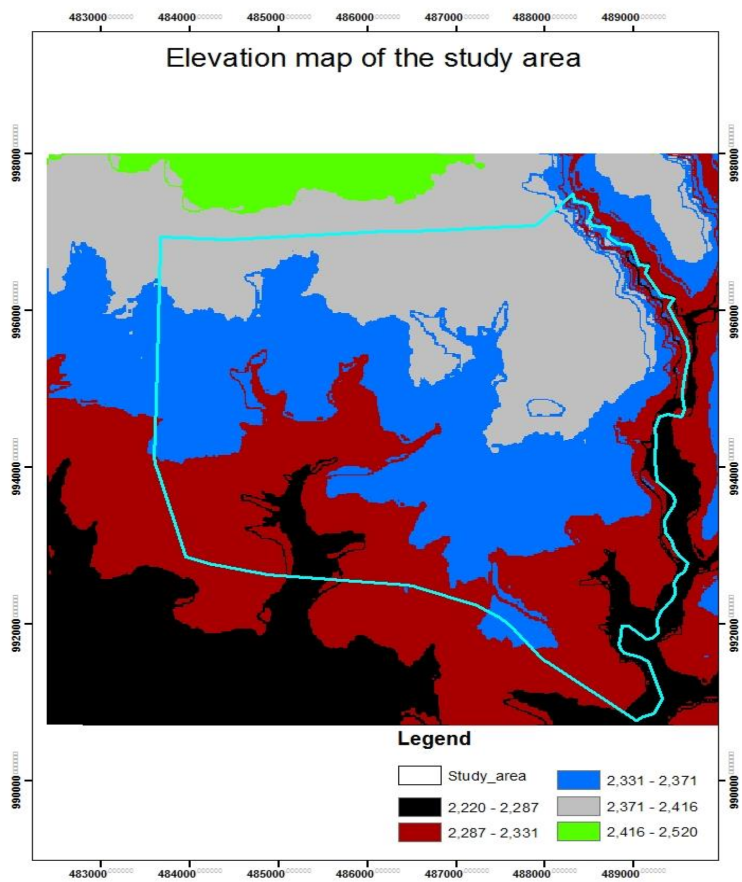

Fig. 3.4 Elevation map of study area

The topography, accompanied with the drainage condition of the study area, also played a major role on the color and distribution of the soils. In relatively gentle and steep slopes of the northern, northeastern, and northwestern parts of the city, light brown to yellowish brown soils are common. These areas are well-drained in favor of the topography. In low lying areas of the city (southern, central, southeastern and western parts), where surface drainage is poor and often water logged, dark colored (dark grey) soils are dominant. In the study area, although small in extent, alluvial soils are found along the course of perennial and intermittent rivers. Further, colluvial soils are also present along the foot hills to the north, northeast and western parts of the city. In general, the topography and drainage of the study area controls the type and distribution of soils considerably. The topographical (elevation) and drainage map of the study area are presented in fig. 3.4 and 3.5 respectively.

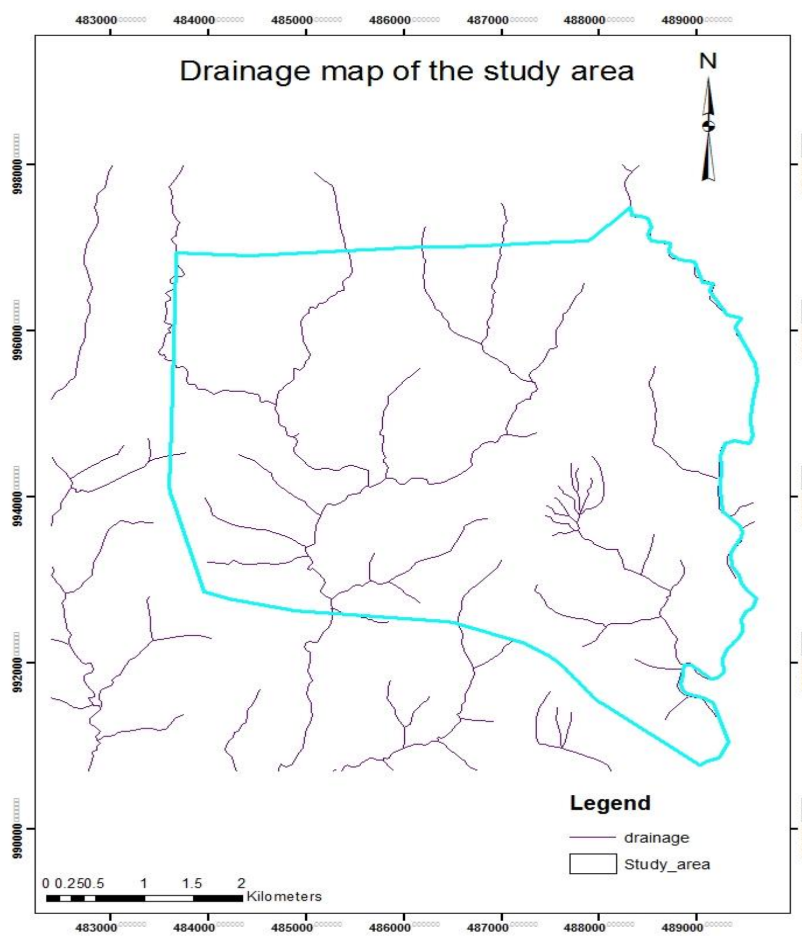

Fig. 3.5 Drainage map of study area

3.5 Climate

Climate is the principal factor governing the rate and type of soil formation. The two most important components of climate are the amount and distribution of precipitation, and temperature. The variable temperature is adequately represented by mean annual temperature, which doesn't differ greatly from the nearly constant temperature in the lower part of the regolith (Gilloth, 1962).

According to Gilloth (1962), the velocity of a chemical reaction increases by a factor of 2 or 3 for every 10 ℃ rise in temperature. The two main rain fall parameters most widely available are the mean annual total and the length of the dry season. The amount and distribution of precipitation affects the availability of moisture and the relative humidity of the soil atmosphere; it influences the concentration or chemical activities of solutions in the system (Gilloth, 1962).

Ethiopia is classified into five climatic zones (Zeleke Tadesse, 2013). These include "Kur" (Alpine), above 3000m mean sea level; "Dega" (Temperate), 2300m to about 3000m; "Weina Dega" (Sub tropical), 1500m to about 2300m; "Kolla" (Tropical), 800m to about 1500m and "Bereha" (Desert), less than 800m. Most parts of Addis Ababa fall under the Weina Dega (Sub tropical) category.

3.5.1 Rain fall

From engineering geological point of view, variations in rainfall brings fluctuations of the groundwater table, thereby producing variations in the moisture content or degree of saturation of the underlying earth materials. The moisture content variation has a greater impact on the engineering properties of earth materials as strength of foundation materials decreases with increase in moisture content. Further, fluctuations in water table may bring cyclic deformational stresses in foundation materials. Most of the time geotechnical investigations are conducted during dry seasons. During such times, sub-surface water level is at a minimum and may not saturate the foundation materials. However, during rainy seasons, the water level raises and weakens the foundation materials. Hence, prior knowledge of rainfall variations helps to understand its impact on ground water table fluctuations and to pass the right decision on the design and long term safety of any engineering structure.

In Addis Ababa, rainfall intensity variation is attributed to differences in Topography. The high elevated areas such as the Intoto receive relatively greater precipitation than lowland areas around Bole and Akaki (Table 3.1).

The mean monthly and annual mean rainfall of National Meteorological Services Agency (NMSA) stations in Addis Ababa located at Addis Ababa Bole (1964 to 2009), Addis Ababa Observatory (Tekelehaimanot) (1900 to 2009) and Akaki Beseka (1951 to 2009) Stations are shown in Table 3.1. All stations are located at elevations of 2350m, 2408m and 2000m a.s.l. respectively.

As indicated in Table 3.1 the precipitation occurs throughout the year and shows variation in amount from month to month. The monthly mean records of rainfall shown for each station indicates that the mean annual rainfall for the years 1900 to 2009 at Addis Ababa Bole, Addis Ababa Observatory (Tekelehaimanot) and Akaki Beseka stations were 1074mm, 1201mm and 1109mm, respectively. Thus, the city receives mean annual rainfall of about 1128mm.

Table 3.1 Mean Monthly and Mean Annual Rainfall of Addis Ababa (1900 to 2009)

Station	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov**	**Dec.**	**Ann. Mean**
A.A. Bole (1964-2009)	13.7	37.4	68.6	93	76.4	119	235.4	242.5	143.3	32.7	7.2	5	1074
Akaki Beseka (1951-2009)	14	36.8	67.5	91	67.1	123	264.1	283.9	131.1	24.5	3.8	3.1	1109
AA Obs T/Haimanot (1900-2009)	16.4	42.9	65.9	93.4	85.5	131	259	278.4	175.1	38.1	7.5	9	1201
Mean Monthly	14.7	39	67.3	92.5	76.3	124	252.8	268.3	149.8	31.8	6.2	5.7	1128

(*Source: National Meteorological Services Agency*)

At all the stations the heaviest rainfall occurs during August whereas the minimum rainfall occurs in December at Addis Ababa Bole and Akaki Beseka stations and in November at Addis Ababa Observatory. Furthermore, Addis Ababa Observatory which is located at a higher elevation than Addis Ababa Bole and Akaki Beseka stations, records greater amounts of mean annual rainfall (1201mm). This shows that there is variation in the amount of rainfall within Addis Ababa with differences in altitude.

Although variation in the amount of rainfall has been recorded in history, it was found difficult to get a direct relationship with the distribution of soil types.

3.5.2 Temperature

Under normal conditions, air temperature decrease with increasing altitude at a mean rate of 0.7 for every 328 feet (Fetter, 1994 as cited in Hana Tibebu, 2008). This works also in Ethiopia where temperature decreases with increasing elevations. The average temperatures are typically tropical to sub-tropical and fluctuate by 50C between the coldest and warmest months. (Griffiths, 1972; as cited in Habtamu Solomon, 2010). Fluctuating temperatures help break down mineral grains in rocks. Warmer temperatures increase chemical weathering. As a result, and being a tropical region, Addis Ababa has thick weathered profile (soil cover) in most of its areas, especially in gentle and flat lands. Although temperature has no direct influence on the engineering properties of foundation materials, its long term effect of accelerating weathering of near surface rocks cannot be denied. Weathering weakens the strength of earth materials through altering the mineralogy as well as their physical properties.

The mean monthly maximum and minimum temperature records of National Meteorological Services Agency (NMSA) stations in Addis Ababa located at Addis Ababa Observatory for the years between 1980 and 2009 were utilized to calculate monthly and annual average temperature. The computed average maximum and minimum temperature is presented in Table 3.2 below.

As can be observed in Table 3.3, the highest monthly average maximum temperature occurs in the months of March with 250C and the lowest is in the month of August with 20.60C.

The monthly average records of temperature shown for each station indicate that the average annual rainfall at Intoto, Addis Ababa Observatory, Addis Ababa Bole, and Akaki stations were 24.20C, 28.20C, 28.10C and 31.40C, respectively. Thus, the city receives mean annual temperature of about 25.60C.

Table 3.2 Monthly and Annual Average Maximum and Minimum Temperatures of Addis Ababa

Station	Jan.	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Ann. Average
Intoto (1989-2006)	19.9	21.1	20.6	20	19.7	17.8	16.2	16.4	16.7	18.2	19.4	18.8	**242.4**
AA Obs (1980-2009)	24.3	25	25.7	24.9	25.3	23.6	21.2	21	22	23.1	23.3	23.1	**282.4**
AA Bole(1980-2008)	23.85	24.7	26	25.1	25.1	23.2	21.1	21	21.7	23.15	23	23	**281.05**
Akaki (1997-2009)	26.5	27.6	28	27.8	28.2	25.9	24.2	24	25.15	26	25.8	25.9	**314.65**
Average Monthly	**23.63**	**24.61**	**25**	**24.45**	**24.57**	**23.7**	**20.67**	**20.6**	**21.4**	**22.61**	**22.9**	**22.7**	**256.34**

(Source: National Meteorological Services Agency)

Furthermore, Intoto station which is located at a higher elevation records smallest amount of average annual temperature. On the contrary, being at lower elevation, Akaki station records the highest amount of average annual temperature. This shows that, like the rainfall, there is also variation in the amount of temperature within Addis Ababa with differences in altitude. However, it is difficult to relate the temperature variation with distribution of soils since temperature effects in a small area cannot be generalized.

3.6 Soil type

The soil development in Addis Ababa area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks. The weathering products are either remain in places and form residual soils or transported and deposited in the low lying flat lands and depressions (Tamiru Alemayehu et al., 2006). The differences observed in the type and development of soils in the city depends mostly on the topography, climate, parent rock and the degree of weathering.

In the localities where the topography is plain to gentle there is thick soil profile. The type of parent material and the length of time to which the parent material is subjected to weathering, control the variation in the thickness of soil. Thus, old basic and acidic rocks that outcrop in the central, western and southwestern parts of Addis Ababa are weathered and form thick soil profile. In places where young basalt and welded tuffs occur, the thickness of the soil cover is reduced (Tamiru Alemayehu et al., 2006).

The detrital materials that are derived from elevated areas of Intoto, Wechecha, Furi and Yerer are transported and deposited in the piedmont and along the stream courses of Addis Ababa. It covers most parts of Mekanisa, Ayere Tena, Kaliti, Akaki, Lideta, and Bole. The soil is black in color and the thickness varies from place to place primarily depending on the slope of the area. More specifically the engineering geological soil unit in Addis Ababa area are grouped into their genetic soil units as alluvial, alluvial fan, colluvial, residual and lacustrine soils (Kebede Tsehayu and Tadesse Hailemariam, 1990) (Fig.3.6).

The alluvial soils which include channel and terrace deposits are found in some places along Akaki River in the west and southwestern parts of Addis Ababa and along Kebena River north of Bole area. The alluvial soils consist of more or less stratified deposits of gravel and clay transported by streams (Kebede Tsehayu and Tadesse Hailemariam, 1990).

Alluvial fan is deposited where there is a decrease in gradient from a hill to a plain along a river section. It is coarser near the mouth of the river and become finer outwards and found in the Intoto region dissected by deep gullies (Kebede Tsehayu and Tadesse Hailemariam, 1990).

Residual soils developed in situ by the decomposition of rocks are mainly located in Gulele and Kolfe area. In some localities reddish brown soil with a thickness of more than 10m is commonly seen.

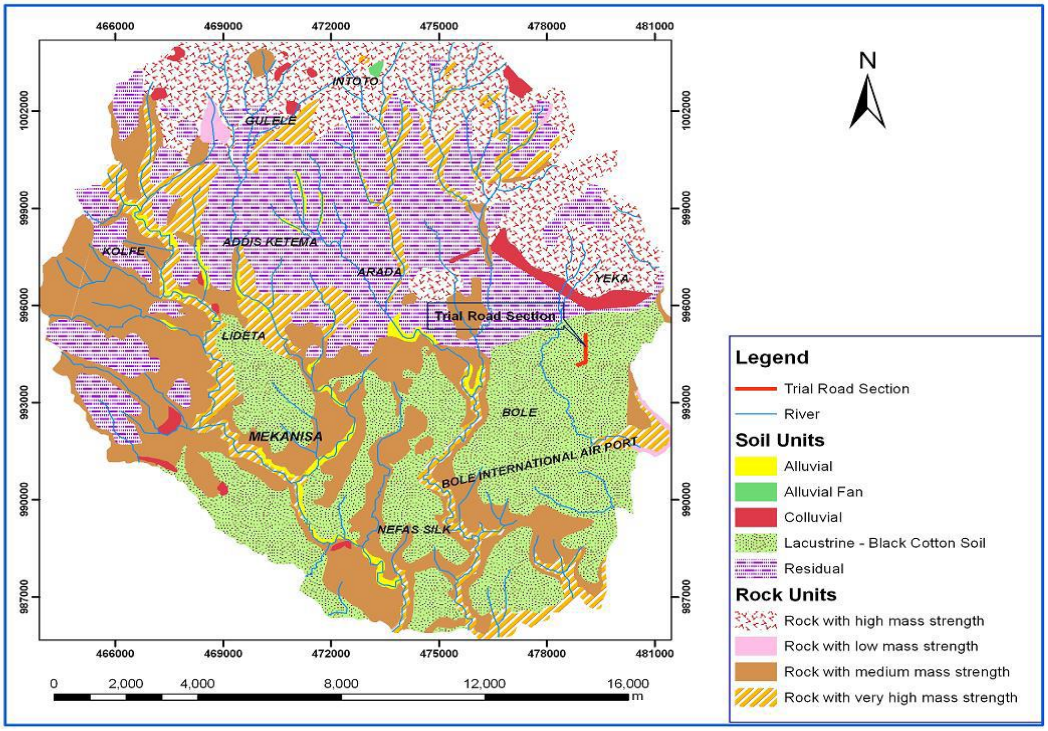

Fig 3.6 Engineering Geological Map of Addis Ababa (Source: from Kebede Tsehayu & Tadesse Haile Mariam, 1990)

Lacustrine soils, alternatively named as black cotton soil, are found in Bole, Lideta and Mekanisa areas as these areas are flat and relatively low lying. Observations and tests show that the low lying flat areas around Addis Ababa are dominated by black cotton soils. These soils have extremely high plasticity and very high degree of swelling as compared to the other identified soil types found in Addis Ababa. The thickness of this soil varies from place to place from 2m to 10m. The highest thickness is found in Bole area and in Beklo Bet area it is about 5m thick (Kebede Tsehayu and Tadesse Hailemariam, 1990).

In areas where there is great contrast in the topography colluvial soils are found. These are loose and incoherent deposits, consisting of fine to coarse grain particles. Colluvial soils are mainly located at the foot slopes of northeastern part of Intoto silicics and other few places.

In the study area two rivers streams exist. One of intermittent nature, Beshale River is flowing from north to south dividing the study area in to two. The other river is Akaki River which bound the study area from North West to south west boundaries of the study area. This could be witnessed from fig.3.5 above. The topography of the study area mostly dominated by slopes from plain to gentle slope. Steep slopes are limited to river banks and their tributaries. And hence the area is poorly drained. In the study area residual soils exist in areas of slopes from flat to gentle and it is observed from test pits/bore holes thick soil profile found around these slopes. The soil layers in the area are heterogeneous justifying their nature of formation which compose clays, silts, sands and gravel. Lacustrine (Black cotton) soil covers most of the flat to gentle areas of the study area. Its thickness reaches to about 6.8m around Beshale 40/60 Condominium site.

CHAPTER FOUR

Methodology

4.1 General

It is essential that a standard language should exist for the description of soils. A Comprehensive description should include the characteristics of both the soil material and the in-situ soil mass. Material characteristics can be determined from disturbed samples of the soil, i.e. samples having the same particle size distribution as the in-situ soil but in which the in-situ structure has not been preserved. The principal material characteristics are particle size distribution (or grading) and plasticity, from which the soil name can be deduced. Secondary material characteristics are the color of the soil and the shape, texture and composition of the particles. Mass characteristics should ideally be determined in the field but in many cases they can be detected in undisturbed samples, i.e. Samples in which the in-situ soil structure has been essentially preserved. Therefore soil description includes details of both material and mass characteristics, and therefore it is unlikely that any two soils will have identical descriptions.

In soil classification/characterization, on the other hand, a soil is allocated to one of a limited number of groups on the basis of material characteristics only. Soil classification/characterization is thus independent of the in-situ condition of the soil mass.

Both soil description and classification require knowledge of grading and plasticity. This can be determined by the full laboratory procedure using standard tests, as described in Sections below, in which values defining the particle size distribution and the liquid and plastic limits are obtained for the soil in question. Alternatively, grading and plasticity can be assessed using a rapid procedure which involves personal judgments based on the appearance and feel of the soil. The rapid procedure can be used in the field and in other situations where the use of the laboratory procedure is not possible or not justified.

Hence various methods were exercised to accomplish the objectives of this research. These are reconnaissance survey of the study area; data collections from secondary sources; primary investigations including filed survey, soil sampling, laboratory testing; systematic data organization and processing; data analysis and interpretations.

Therefore in this chapter details of the methodologies exercised to achieve the research paper objectives are explained.

4.2 Data presentation

4.2.1 Reconnaissance site survey

From reconnaissance site survey, observation on out crop/excavated formation and soil layer at cut areas, topography and drainage condition of the area and distribution of constructions, damages observed in construction carried in the area have been done.

The information on distribution of construction sites used to identify secondary data sources and soil layer variation along depth on excavated ongoing construction sites. The information on out crops, cut excavated sites used in x-section work for analysis of soil profile in the research area. Information on topography and drainage conditions of the area are used to relate with the different maps collected from secondary sources for verification of site condition.

The root of the survey was from Ayat Square to Aribazetegn Mazoria, from Ayat Square to Bole Arabsa through Summit and Beshalle 40/60 condominium site. It also incorporates the area from Ayat Square along Yetbaberut Gas Station, Pepsi and to Summit.

4.2.2 Secondary data

For ease of identifying primary data locations to be distributed evenly, secondary data from different institutions and organization working in the area have been collected. These data include bore holes data, information on grain size distribution, liquid limit, plastic limit, plasticity index, specific gravity, natural moisture content, unconfined compression strength (UCS) results, shear strength (c-phi) and compression coefficient and initial void ratio. Total of 66 borehole logs and 10 test pit logs collected from various private and government organization working in the study area.

4.2.3 Primary data

4.2.3.1 Disturbed

Transect walk carried across the study area and secondary data collected and analyzed so that locating of primary data pits could be facilitated. Three pit location one in each of bole Arabsa, Ayat and Summit area determined.

Six disturbed samples were collected from these pits at depths of 1.5 and 3 meters. The samples collected carried to the soil lab center named EJ Engineering for index property determination which includes Natural moisture content, Specific gravity, dry Sieve analyses (particle size distribution), Atterberge limits(LL, PL,PI).

4.2.3.2 Undisturbed

Three undisturbed samples at a depth of 4m extracted from test pits (ongoing constructions) by use of Shelby tube. The samples immediately after extraction wax sealed and covered by polyethylene tube. These samples carried to EJ Engineering soil laboratory for determination of engineering properties which include unconfined compressive strength (UCS), compaction, Consolidation and permeability tests.

4.2.4 Exposed/excavated surface data

Exposed/excavated surface data were collected by picture and hand operated GPS so that x-section profile work could be facilitated well. These data are used as a means to fill gap of data shortage. Total of four excavated sites were taken by picture and hand GPS so that soil profile of the area could be anticipated.

Table 4.1 Secondary Test Pit Locations

S/No	New TP ID	East	North	Elevation	S/No	New TP ID	East	North	Elevation
1	STP - 1	487739	993107	2438	6	STP - 6	487386	994168	2358
2	STP - 2	487740	993129	2438	7	STP - 7	485310	994697	2326
3	STP - 3	487756	993127	2438	8	STP - 8	487662	996576	
4	STP - 4	487736	993183	2438	9	STP - 9	484896	996797	2314
5	STP - 5	487715	993124	2438	10	STP -10	484500	996649	2395

Table 4.2 Secondary borehole location

S/No	New BH ID	East	North	Elevation	S/No	New BH ID	East	North	Elevation
1	SBH-1	487415.9	994180.1	2104	61	SBH-61	486544	995823	2382
2	SBH-2	487478.5	994147	2105	62	SBH-62	486756	995315	2372
3	SBH-3	487593.4	994187.5	2117	63	SBH-63	487869	996035	2394
4	SBH-4	488521.2	995651.6	2388	64	SBH-64	484944	995200	2364
5	SBH-5	487911.1	996137.4	2398	65	SBH-65	487680	996704	2404
6	SBH-6	488364.2	995514	2387	66	SBH-66	487829	995025	2365
7	SBH-7	488355.2	995378.7	2389	34	SBH-34	484313	994970	1996.91
8	SBH-8	488524.7	995447.3	2388	35	SBH-35	484400	995053	1990.68
9	SBH-9	488508.8	995540	2391	36	SBH-36	484425	995116	1986.26
10	SBH-10	488538.9	995235.9	2383	37	SBH-37	485521.1	995937.4	2370.22
11	SBH-11	488776.1	995307.4	2390	38	SBH-38	485580	995917.3	2372.65
12	SBH-12	488929.5	995301.7	2390	39	SBH-39	485612.7	995919.7	2372.99
13	SBH-13	488485.1	994969.2	2394	40	SBH-40	485640.4	995902	2371.83
14	SBH-14	488934.4	995450.2	2391	41	SBH-41	485701.6	995862.1	2369.2
15	SBH-15	488929.9	995526	2391	42	SBH-42	487869	996532	2340
16	SBH-16	488922.9	995857.1	2390	43	SBH-43	487854	996534	2340

17	SBH-17	488899.6	995931.3	2391	44	SBH-44	487873	996526	2340
18	SBH-18	487241	994217	2368	45	SBH-45	487297	996054	2285
19	SBH-19	487183	994044	2365	46	SBH-46	487282	996061	2285
20	SBH-20	487072.6	993805.9	2361	47	SBH-47	487792	996875	2340
21	SBH-21	487024.1	993809.1	2360	48	SBH-48	487801	996885	2340
22	SBH-22	486822.9	993955.5	2357	49	SBH-49	487723	995903	2340
23	SBH-23	486739.1	993948.2	2352	50	SBH-50	487714	995919	2340
24	SBH-24	486888.4	994104	2360	51	SBH-51	485623	996875	2392
25	SBH-25	486973.6	993959.5	2361	52	SBH-52	485653	996884	2392
26	SBH-26	486921.7	993989.6	2360	53	SBH-53	487714	994370	2365
27	SBH-27	486880.4	994148.4	2357	54	SBH-54	487758	994359	2366
28	SBH-28	487010.3	994091.7	2362	55	SBH-55	488103	994366	2369
29	SBH-29	487129	994118	2365	56	SBH-56	488227	994372	2359
30	SBH-30	486519.2	992761.8	2358	57	SBH-57	488165	994331	2367
31	SBH-31	487403	992449.8	2330	58	SBH-58	488164	994261	2372
32	SBH-32	484185	994965	2001	59	SBH-59	487691	994285	2361
33	SBH-33	484238	994884	1999.78	60	SBH-60	487712	994305	2362

Table 4.3 Exposed/excavated surface profile locations

S/No	ID	East	North	Elevation
1	EX - 1	484528	992966	2314
2	EX - 2	487705	996042	2382
3	EX - 3	487324	996051	2394
4	EX - 4	486078	996061	2383

Table 4.4 Primary data pit locations

S/No	ID	East	North	Elevation
	PTP - 1	487949	997140	2403
	PTP - 2	487805	992997	2330
	PTP - 3	485046	995366	2362

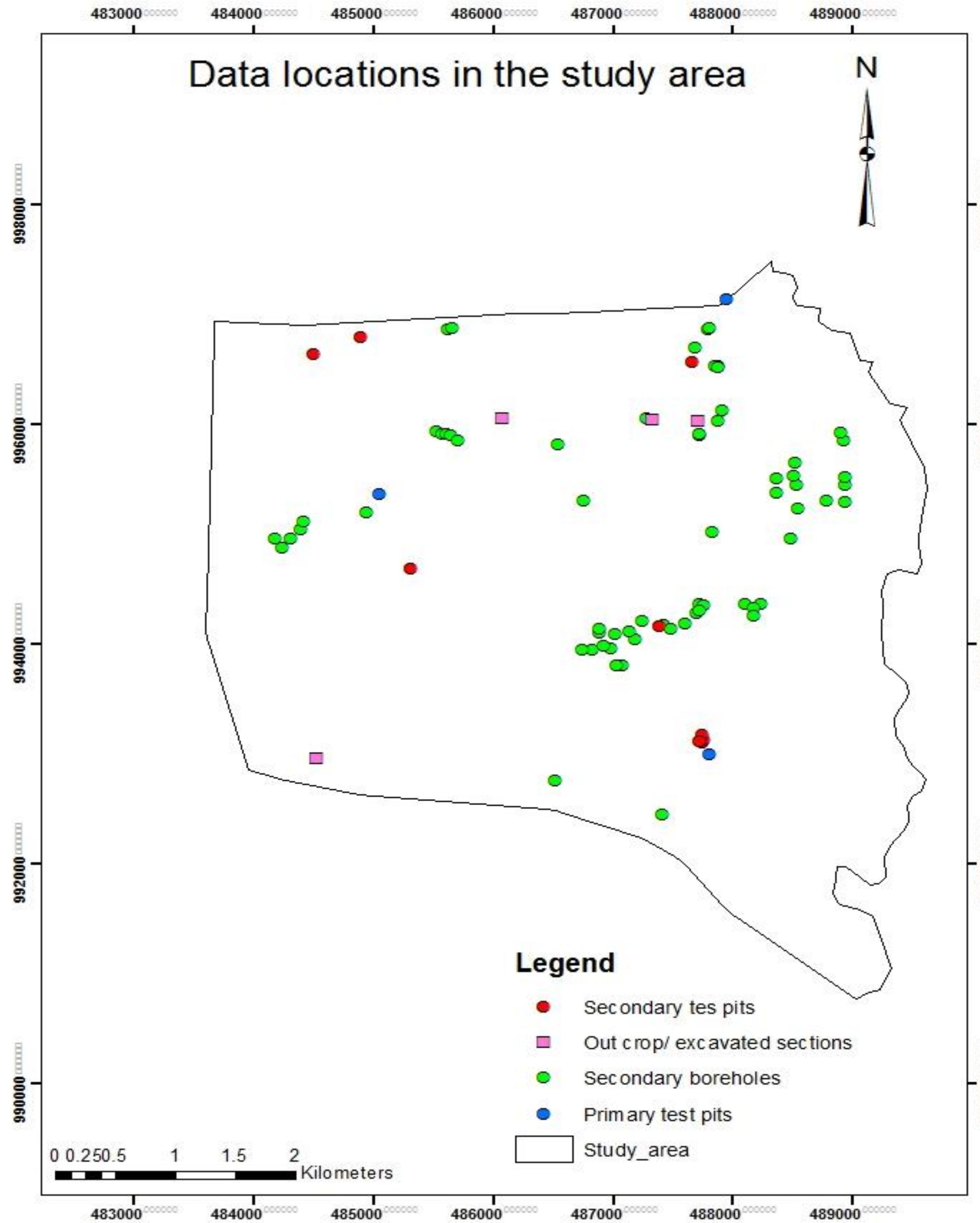

Fig. 4.1 Map showing locations of secondary, primary and excavated surface profile data (borehole and pit).

CHAPTER FIVE

Result Discussion

5.1 General

In the study area soil are variable with variable depth and space. Different soil emerging one layer after the other with fine material at top and gradually with increasing grain sizes. In most cases Silty clay layer followed by Silty sand and weathered material are witnessed from data organized for the research area. This is the case for residual soil in which soils formed in-situ by the weathering of the parent material.

The topography of the research area is of plain to gentle slope nature and steep slopes are limited to the stream banks. Therefore movement of the soil is limited in the study area leading to formation of residual soil. Moreover the upper most layer of most of the research area is covered by black cotton soil (lacustrine soil) with dark to grey color and high plasticity and expansive nature which is the case for poorly drained conditions; the condition for the research area.

5.2 Result Discussion

5.2.1 General

The laboratory test results for moisture content, specific gravity liquid limit, plasticity limit and free swell show that there is wide variable value of range. This is not only on spacial bases but on depth bases too. These makes soil characterization of the study area very hard. Even with in the same layer of soil profile more soil types are found. Even the soil of one family has very variable test results of moisture content, specific gravity and free swell. Besides in the review of geotechnical reports of AASHDE (40/60) condominium projects in the area it is evident to find cases where a building block foundation rest on different soil types on spacial bases.

The results of the index test show that four soil types are dominantly exist in the study area. These soil in their order of abundance of occurring are MH, ML, SM and CH. The other soil types CL, GM, SC, CL – ML, & SC – SM area rarely exist in the study area.

5.2.2 Laboratory test results

5.2.2.1 Index properties

General

Naturally soil is very erratic. It may vary even in very short distance both in terms of horizontal space and depths. However soils showing similar behavior/characteristic can be grouped under specific group. This could be achieved by simple tests without carrying expensive, tedious and elaborated engineering tests.

These tests give indirect information about engineering properties and hence termed index test. These simple tests are classification tests. Soil is classified based on index properties which are identified by index tests. Index tests include Natural moisture content, Specific gravity, consistence limits, Grain size analysis, free swelling of the soil.

For the identification of index properties nine samples from disturbed samples and three from undisturbed samples of three pits (ongoing construction projects) located in different locations of the study area at depths of 1.5, 3 and 4 meters were harvested and taken to EJ Engineering soil lab for laboratory test. And in this research the index test carried include specific gravity, Natural moisture content, Particle size distribution (sieve analysis), Atterburg limits (liquid limit, plastic limit and plasticity index).

Natural moisture content

Natural moisture content data of amount 96 at various depths from secondary sources and 9 from primary sources of which six are from disturbed and three from undisturbed samples have been incorporated in this thesis.

AASHTO T-265 Standard Test for Natural Moisture Content of soil is used for determination of the natural moisture content of soil.

For undisturbed primary samples brought to the laboratory and measuring the weight of moisture can and weight of the can with moist soil put in to drying oven at a temperature of 105+5°c for 24 hours. Then after, the natural moisture content was determined. Necessary cares were taken during undisturbed sample collection stages, the top and bottom of the Shelby sample taking tube were immediately wax sealed and covered with polyethylene bags that are labeled with necessary information for natural moisture content and other subsequent laboratory tests.

For disturbed samples, this test was done by taking moisture can and balance to the field. At the site the weight of the moisture can and the weight of can with moist soil was measured. Then the sample was brought to the laboratory and put in to drying oven at a temperature of 105+5°c for 24 hours. Then after, the natural moisture content was determined.

The test result of natural moisture content of the study area ranges from 5.47 to 67.37 % with data average of 31.79%.

Specific gravity

Specific gravity data of amount 77 from secondary sources and 9 from primary source have been incorporated in this thesis.

The tests were conducted according to AASHTO 084-94 test procedures (Primary data). According to the test procedures there are two methods for performing specific gravity. These are Method-A, procedures for oven dried specimen and Method-B, procedure for moist specimen. For specimens of organic soils and highly plastic, fine-grained soils procedure B shall be the preferred method. In this thesis work Method-B is the preferred method referring the sample type.

Specific Gravity of soil solids of the study area ranges from 2.03 to 2.87 % with data average of 2.58.

Grain size distribution

Sieve analysis data of amount 159 from secondary sources and 9 from primary sources have been incorporated in this thesis.

AASHTO T - 88 Standard Test Method for particle size analysis of soil is used for determination of the particle size distribution of soil.

According to the test result of soil in the study area; fine grain ranges are from 10.7% to 99.6%, with an average of percent fine 68.95% which indicates the soil in the area is dominated by fines.

Atterberg Limits

AASHTO T – 89 & 90 Standard Test Method for Liquid limit, Plastic limits and Plasticity index of soil is used for determination of the Liquid limits, Plastic limits and Plasticity index of soil. Atterburg limit test data of amount 231 from secondary and 9 from primary sources have been incorporated in this thesis. According to the test results Liquid limits ranges from non-plastic to 116%, plastic limits non-plastic to 84%, Plasticity index non-plastic to 73% with an average data value of 51%, 28.34 and 22% consecutively. Based on the data average of moisture content the soil in the area was on the plastic state.

Free swell

To study the swelling property of the soils, the simplest test conducted is free swell test. The test is conducted by adding 10ml of dry soil passing No.40 sieve into 100ml graduate cylinder filled with distilled (tap) water. After 24 hours, final volume of the suspension being read.

Total of 110 data from secondary and 9 from primary sources were incorporated in this thesis.

The free swell of the soil is then determined as a ratio of the change in volume to the initial volume. The free swell of soils of the study area ranges from non-swelling to 200% with an average data value of 60.4% which is above 50% indicating that the soil in the area is marginally expansive.

5.2.2.2 Engineering Properties

Shear Strength of the Soil

The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside it. One must understand the nature of shearing resistance in order to analyze soil stability problems, such as bearing capacity, slope stability, and lateral pressure on earth-retaining structures. (Das, 2007).

The most common laboratory methods employed to obtain shear strength parameters are direct shear test, triaxial compression test and unconfined compression test (UCS). For this thesis UCS test are conducted and direct shear test result from secondary data incorporated.

A. Unconfined compression test (UCS)

Unconfined compression test is a one of the simplest and quickest test used for the determination of shear strength of cohesive soils (Murthy, 1990).

The UCS tests were conducted according to AASHTO T-208 test procedure for determination of the unconfined compression strength of soils.

Total of 39 data from secondary and 3 data from primary sources are incorporated in this thesis.

Compressive strength of soils of the study area ranges from 25.94kN/m2 – 285kN/m^2 indicating to have a consistency of soft to very stiff. The area has an average UCS data of 99.6 KN/m^2 indicating the soil in the area has consistency of stiff averagely.

B. Direct shear

From 3 secondary data the cohesion (C) of study area soil ranges 34 - 44 KN/m2 and angle of internal friction (Φ) ranges from 15^0 – 17^0.

Compaction Test

In the construction of highway embankments, earth dams, and many other engineering structures, loose soils must be compacted to increase their unit weights. Compaction increases the strength characteristics of soils, which increase the bearing capacity of foundations constructed over them. Compaction also decreases the amount of undesirable settlement of structures and increases the stability of slopes of embankments. (Das, 2007)

Compaction, in general, is the densification of soil by removal of air, which requires mechanical energy. The degree of compaction of a soil is measured in terms of its dry unit weight. When water is added to the soil during compaction, it acts as a softening agent on the soil particles. The soil particles slip over each other and move into a densely packed position. The dry unit weight after compaction first increases as the moisture content increases. Eventually it reaches a limit beyond which an increase of moisture content tends to reduce the dry unit weight. This phenomenon occurs because the water takes up the spaces that would have been occupied by the solid particles. The moisture content at which the maximum dry unit weight is attained is generally referred to as the optimum moisture content.

The laboratory test generally used to obtain the maximum dry unit weight of compaction and the optimum moisture content is called the Standard Proctor compaction test.

Laboratory Standard proctor compaction test was used according to AASHTO T-180 to determine the maximum dry density and optimum moisture content of soil under investigation.

Total of 3 data from primary sources are incorporated in this thesis.

The maximum dry density (MDD) of the study area ranges from 1.67 to 1.7 g/cm3 and the optimum moisture content ranges 18.5 to 23.4 %.

Consolidation

Three undisturbed primary samples were taken at Ayat, Summit & Bole Arabsa areas. Nine secondary sample test results taken from secondary data sources and these samples were taken at various depths below natural ground level.

The odometer tests were to be conducted according to AASHTO T-216 test procedures. But the samples collected found to be non-plastic hence consolidation theory couldn't hold for and hence abandoned.

From the secondary test results the initial void ratio (e_o) of soil in the study area ranges from 0.7-1.52 and the compression index (Cc) ranges 0.09 to 0.336.

Permeability

Soils are permeable due to the existence of interconnected voids through which water can flow from points of high energy to points of low energy. The study of the flow of water through permeable soil media is important in soil mechanics. It is necessary for estimating the quantity of underground seepage under various hydraulic conditions, for investigating problems involving the pumping of water for underground construction, and for making stability analyses of earth dams and earth-retaining structures that are subject to seepage forces. (Das, 2007).

Two standard laboratory tests can be used to determine the hydraulic conductivity (permeability) of soil—the constant-head test and the falling-head test. For this thesis work falling head permeameter test is conducted.

Standard laboratory procedures for determination of permeability of soil AASHTO T-208 & 215 is followed in the test.

The coefficient of permeability results of the test in the study area ranges from 2.8 to 5 (x 10-3) cm/sec. This result indicates the soils of the area are greater that 10^{-3} mm/sec hence are pervious.

5.2.3 Classification of the soil

5.2.3.1 Unified Soil classification system

The soil in the study area is classified according to this classification system. In the area the dominant soil are MH, ML, SM and CH.

5.2.3.2 Plasticity chart

The plasticity chart for some of the soils is tried to be shown in the plasticity chart below.

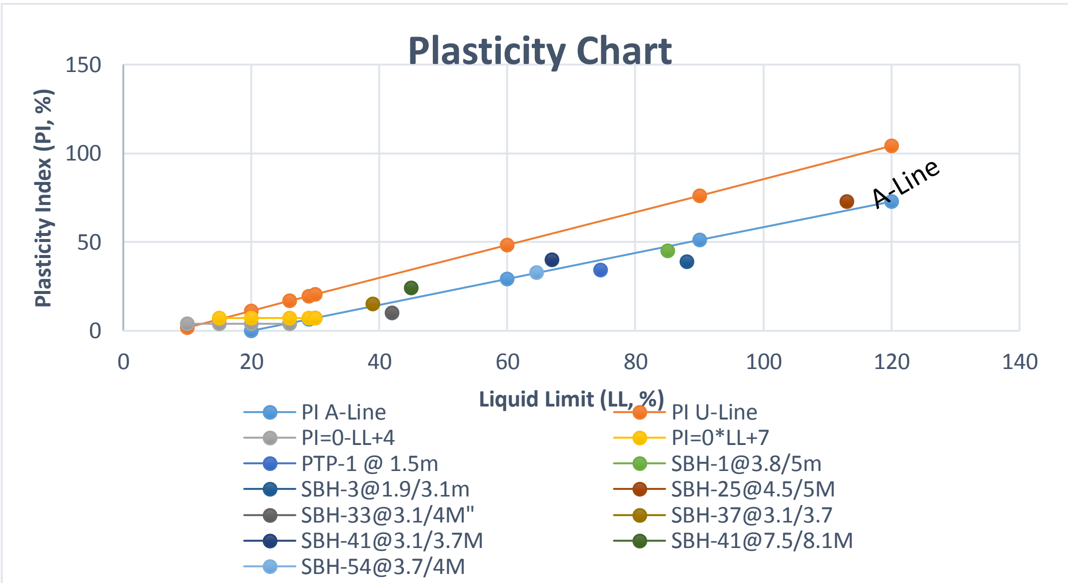

Fig. 5.1 Plasticity chart for some of soil in the study area

5.2.4 Correlation of index with engineering properties of identified soil

5.2.4.1 General

In order to develop relationships between particles passing 200 sieve (P_{200}), liquid limit (LL), plasticity index (PI) and unconfined compression strength (UCS) regression analyses were used. Regression analysis is normally used to create a mathematical model that can be used to predict the values of a dependent variable based upon the values of an independent variable. To perform the regression analyses, test data was plotted in 2 dimensions as a scatter plot. This format allows visualization/inspection of the data prior to running a regression analysis. Different curve fitting relationships, such as linear, exponential, logarithmic, polynomial, and power, can be used to analyze the relationship between a dependent and independent variable. The curve fitting relationships produce a coefficient of determination (R^2). The coefficient of determination is the measure of the proportion of variability on one variable that can be accounted for by variability on the other variable (Sheskin, 2000 as sited in Farah, Raoaa, (2011) MSc Thesis on "Correlations between Index Properties and Unconfined Compressive Strength of Weathered

Ocala Limestone"). Once all possible regression curve fits and associated R^2 values have been determined, a researcher will then decide which curve fit is most appropriate. Typically the most appropriate curve fit is the one with the highest R^2 value. Based on literature linear or exponential curve is expected between UCS and each of P_{200}, LL and PI.

Regression analysis was made for data of different soil types in the study area. The regressing is carried between independent variables P_{200}, LL, PI and dependent variable UCS. Different curve fittings have been tried and presented together with their predictive model equation and its coefficient of determination (R^2). But the curves other than linear and exponential are only mathematical which couldn't serve practical situations and therefore left even though they show better R^2.

5.2.4.2 MH (Highly plastic silts)

It is the most dominant soil in the study area. It is seen in 42 SBH's, 3 STP's and 1 PTP at variable depths. From index tests the soil has particles passing 200 sieve ranges from 54% to 99.6% with average value 85.04%, liquid limit and plasticity index 50% to 116% and 7 to 66% with average value78.62% & 35.39% respectively. Moisture content for the soil ranges from 5.65 to 67.37% with average value 37.42%. Specific gravity ranges 2.03 to 2.84 with average value 2.53. Free swell range non swell to 200% with average value 84.62% showing the soil varies from non-expansive to expansive soil.

From engineering tests the soil has UCS ranges from 25.94 to 206KN/m^2 and average value of 95.69KN/m^2 indicating the soil varies from soft to very stiff consistency. Compressibility index and initial void ratio ranges 0.12 to 0.336 and 0.907 to 1.29. The summary of laboratory test result of this soil is attached in appendix A-2.

An attempt to estimate the UCS was made by making use of P_{200}, LL and PI alternatively. The curves; exponential, linear, logarithmic, polynomial and power are tried for each match of relations as could be seen below.

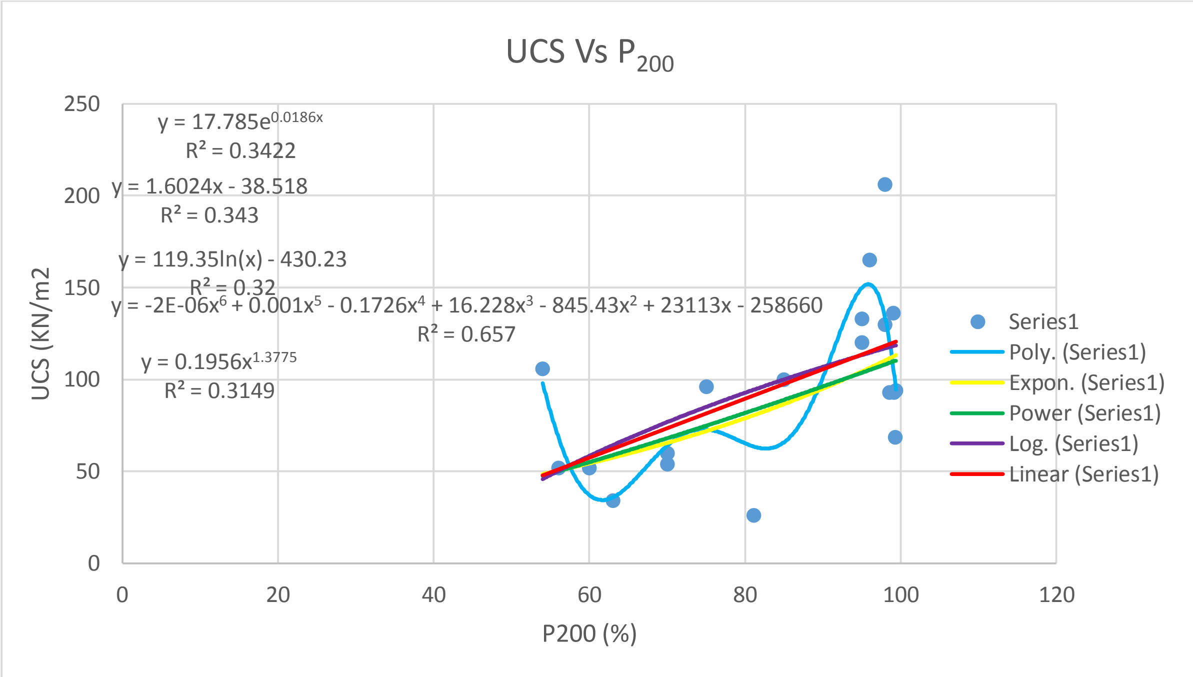

Fig 5.2 Regressing Graph UCS Vs P_{200} MH soil

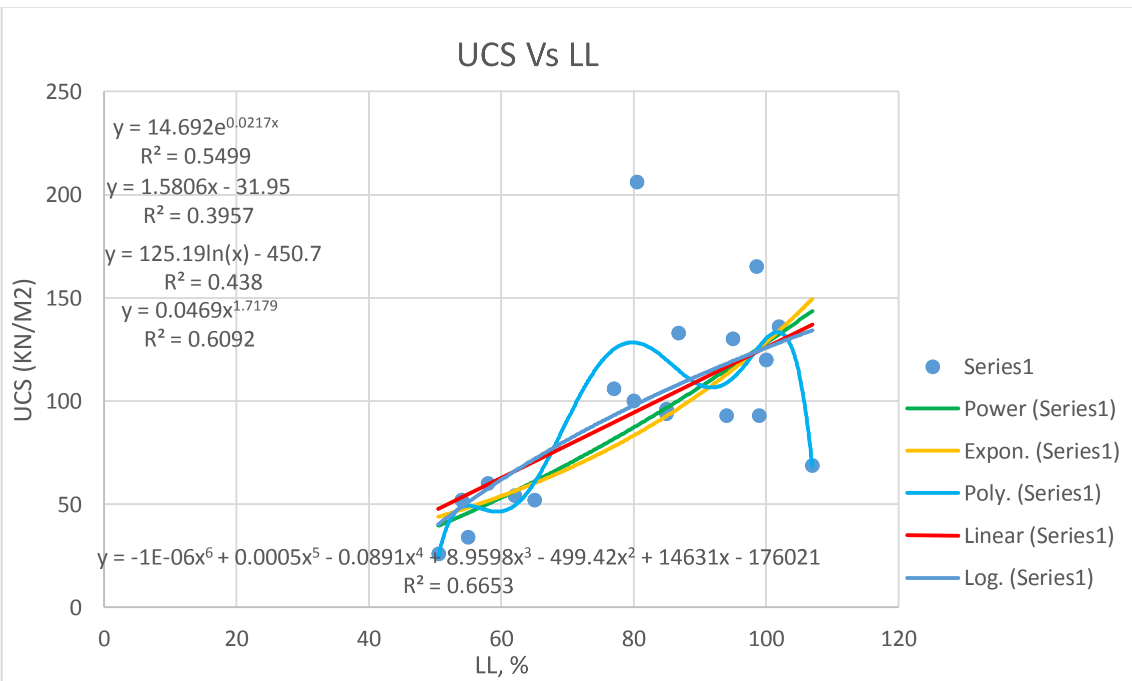

Fig 5.3 Regressing Graph UCS Vs LL, MH soil

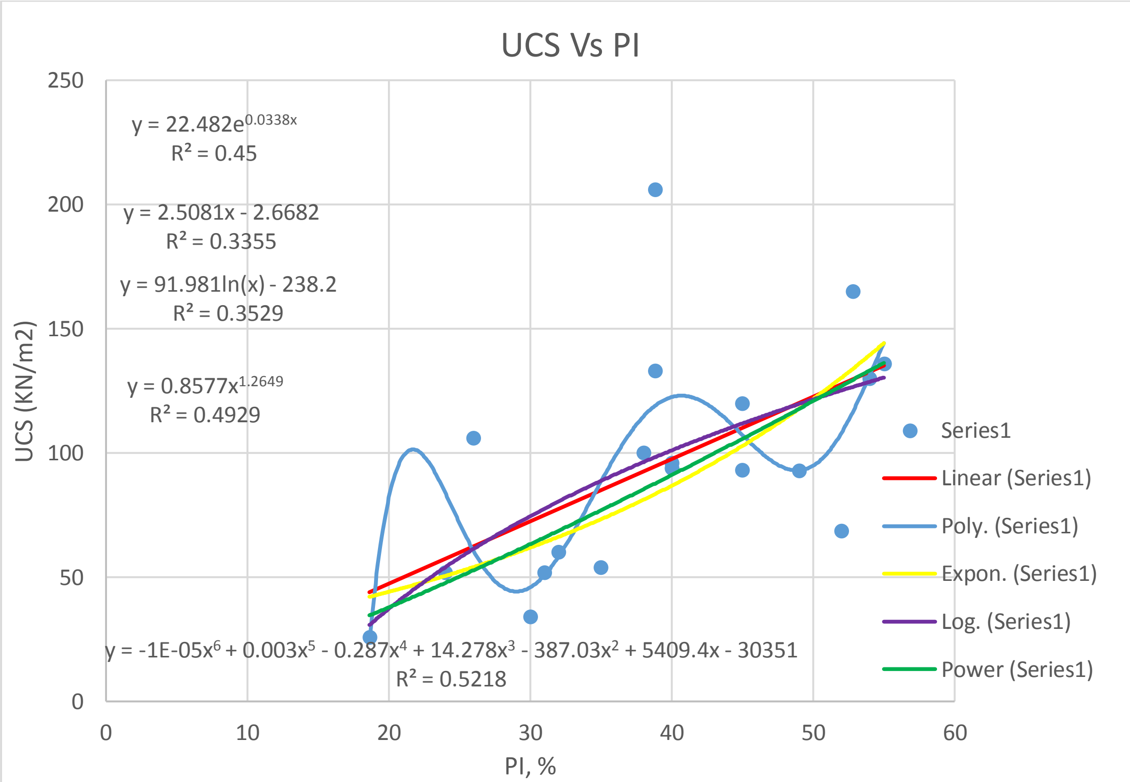

Fig 5.4 Regressing Graph UCS Vs PI, MH soil

The 6th order polynomial curve for the relation between UCS vs P_{200}, UCS vs LL and UCS vs PI with R^2 value of 0.552, 0.6653 and 0.5218 show better relation which is only mathematical that couldn't suffice practical usage. Besides the power curve and the exponential curves for the relation between UCS vs LL show better relation with R^2 value of 0.6092 and 0.5499 respectively. So from the trial curves the unconfined compressive strength can be predicted better by using the exponential equation which incorporated liquid limit (LL) as independent variable. The models and curve fitting of the scattered graph are presented on fig 5.2 through 5.4.

5.2.4.3 ML (Low plastic silt soil)

It is the second most dominant soil in the study area. It is seen in 21 SBH's, and 3 PPT's at variable depths. From index tests the soil has particles passing 200 sieve ranges from 51.9% to 93.3%, liquid limit and plasticity index 0% to 65% and 0 to 32.69 respectively. Moisture content tests for the soil ranges from 12.08 to 48.17%. Specific gravity ranges 2.48 to 2.68, free swell range non swell to 145% showing the soil varies from non-expansive to expansive soil. The average data values for the properties percent fine, liquid limit, plasticity index, moisture content, specific gravity and free swell are 69.6%, 26%, 8.6%, 28.1%, 2.6 and 23.5.

From engineering tests the soil has UCS ranges from 34 to 200KN/m^2 and average value of 80.7KN/m^2. This indicates the soil varies from soft to very stiff consistency. The soil can be compacted to maximum dry density of 1.67 to 1.7 g/cm3 at an optimum moisture content of 18.5 to 19.5%. Compressibility index and initial void ratio values of 0.12 and 1.52. The soil has permeability coefficient 2.8 to 5 ($x10^{-3}$) cm/sec indicating the soil is pervious. The summary of laboratory test result of this soil is attached in appendix A-3.

An attempt to estimate the UCS was made by making use of P_{200}, LL and PI alternatively. The curves, exponential, linear, logarithmic, polynomial and power are tried for each match of relations as could be seen below.

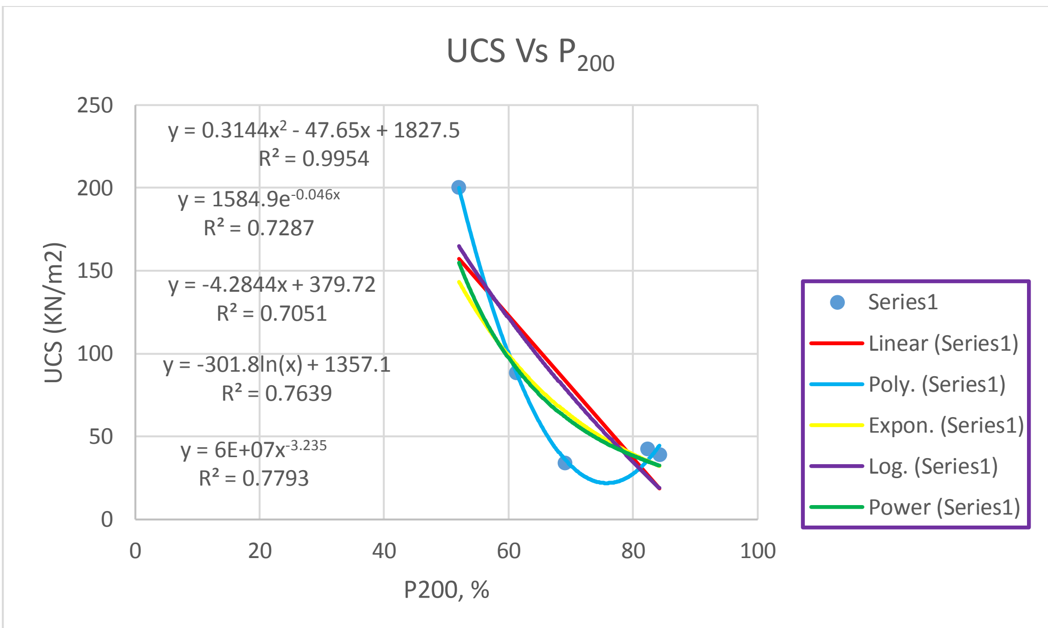

Fig 5.5 Regressing Graph UCS Vs P_{200}, ML soil

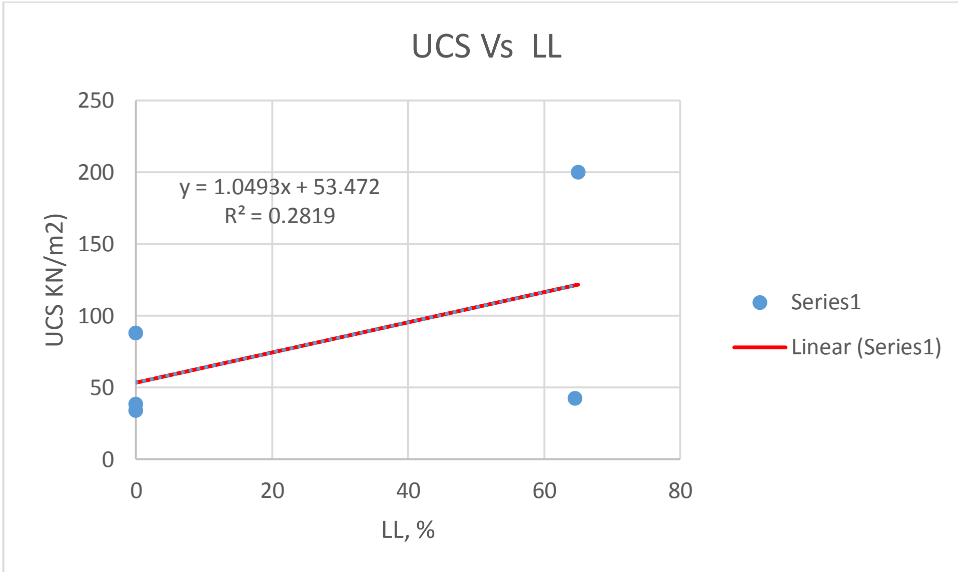

Fig 5.6 Regressing Graph UCS Vs LL, ML soil

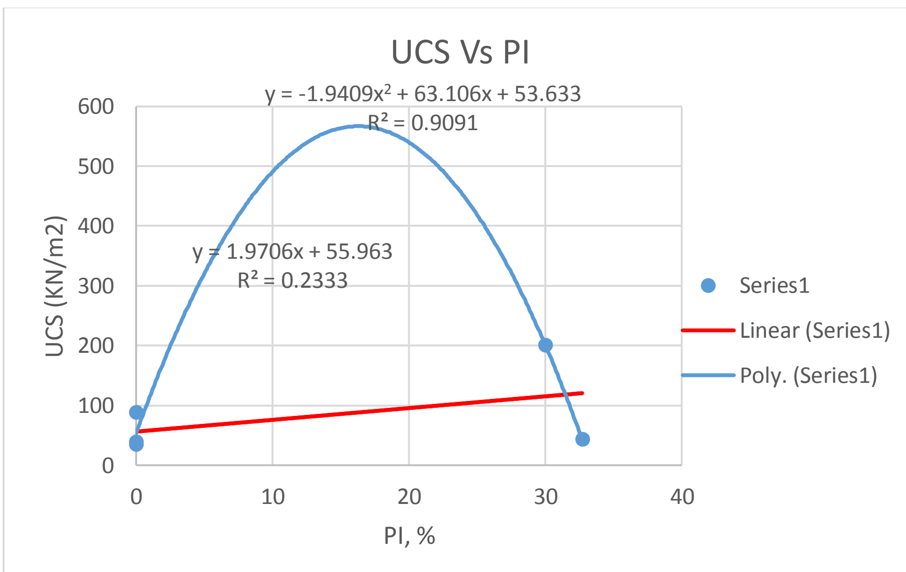

Fig 5.7 Regressing Graph UCS Vs PI, ML soil

All the five trial curves (exponential, linear, logarithmic, 2nd order polynomial and power) for the relation between UCS vs P_{200} are show better relation with R^2 value 0.7287, 0.7051, 0.7639, 0.9954 and 0.7793 respectively. For the relation between UCS vs LL none of the trials are acceptable. Second order polynomial was found to be sound for the relation between UCS vs PI with R^2 value of 0.9091. Among these all trial curve the best models for UCS determination are exponential and linear curves with P_{200}. Although all these curves are tried and the results show better coefficient of determination (R^2) around 0.7278 and 0.7051 for P_{200}, the regression is based on limited size of data (five pairs). And this makes the model luck credibility.

5.2.4.4 SM (Sandy silts)

It is the third most dominant soil in the study area. It is seen in 20 SBH's, and 3 PTP's at variable depths. From index tests the soil has particles passing 200 sieve ranges from 11.8% to 47%, liquid limit and plasticity index non plastic to 71% and non-plastic to 31 respectively. Moisture content tests for the soil ranges from 11.04 to 51.71%. Specific gravity ranges 2.16 to 2.8, free swell range non swell to 70 % showing the soil varies from non-expansive to marginal soil.

From engineering tests the soil has UCS ranges from 40.7 to 285 KN/m^2. The soil can be compacted to maximum dry density of 1.7 g/cm^3 at an optimum moisture content of 23.4 %. Compressibility index and initial void ratio values of 0.12 and 1.14 are seen. The soil has permeability coefficient 3.6 x 10^{-3} cm/sec indicating the soil is pervious. The summary of laboratory test result of this soil is attached in appendix A-5.

For SM soil all five trial curves have been tried but their coefficient of determination (R^2) are below 0.1.

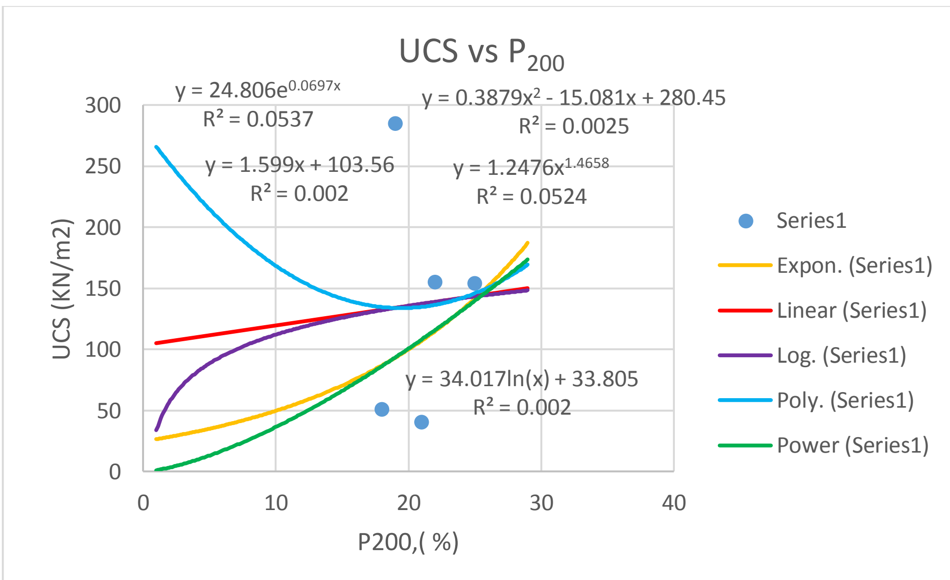

Fig 5.8 Regressing Graph UCS Vs P_{200}, SM soil

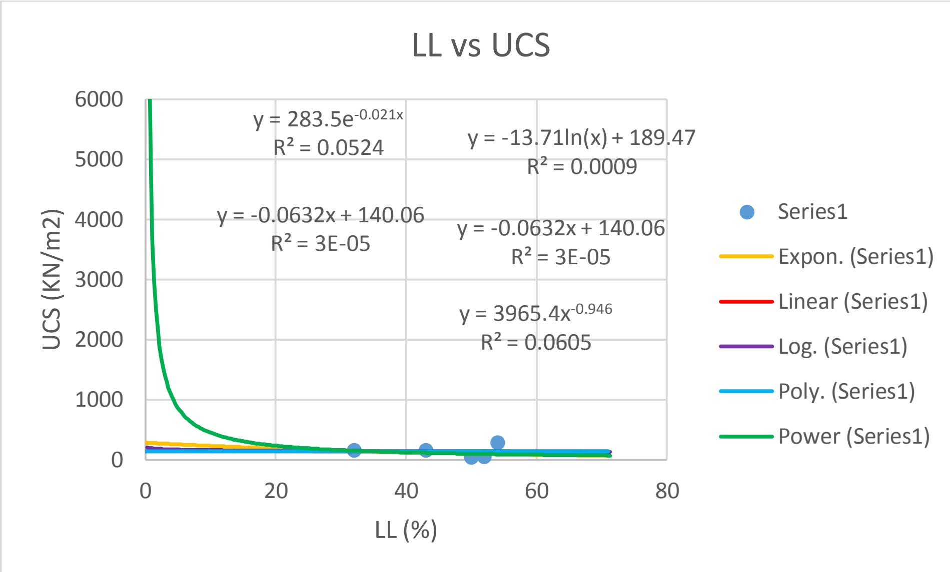

Fig 5.9 Regressing Graph UCS Vs LL, SM soil

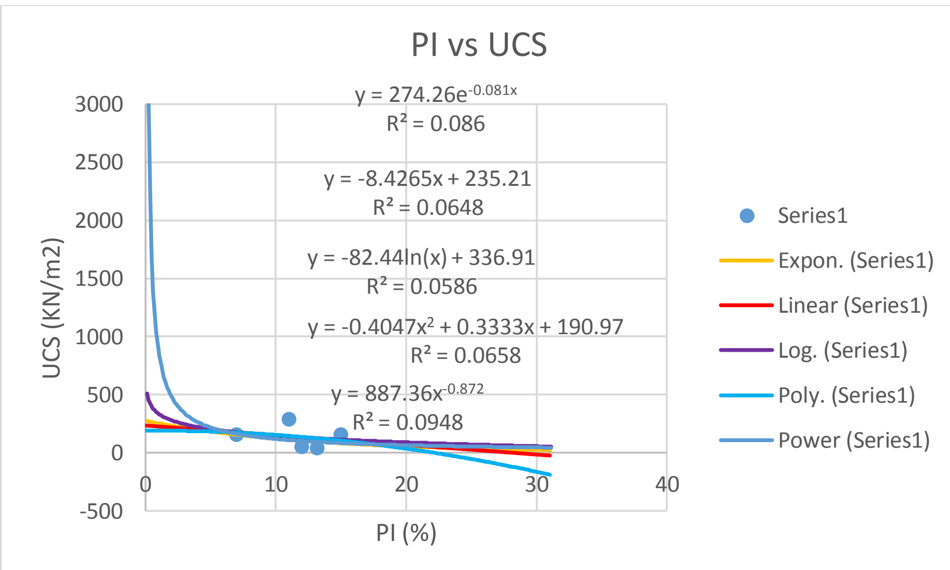

Fig 5.10 Regressing Graph UCS Vs PI, SM soil

This show that there is no relation seen between UCS and each of the three separate independent variables; P_{200}, LL and PI.

5.2.4.5 CH (High plastic clays)

It is the fourth most dominant soil in the study area. It is seen in 20 SBH's, and 1 SPT at variable depths. From index tests the soil has particles passing 200 sieve ranges from 50.98% to 99.4%, liquid limit and plasticity index 53% to 113% and 24 to 73 respectively. Moisture content tests for the soil ranges from

24.82 to 51.49%. Specific gravity ranges 2.19 to 2.84, free swell range 10 to 200% showing the soil varies from non-expansive to highly expansive soil.

From engineering tests the soil has UCS ranges from 40 to 270KN/m^2. Indicating the soil varies from soft to very stiff consistency. The summary of laboratory test result of this soil is attached in appendix A-4.

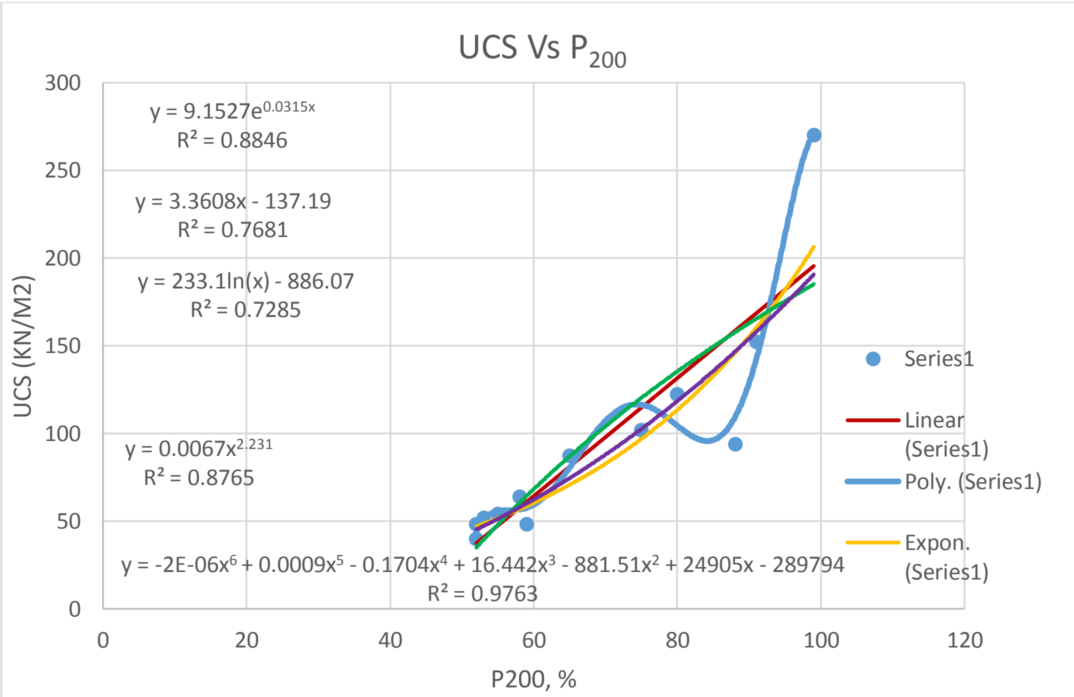

Fig 5.11 Regressing Graph UCS Vs P_{200}, CH soil

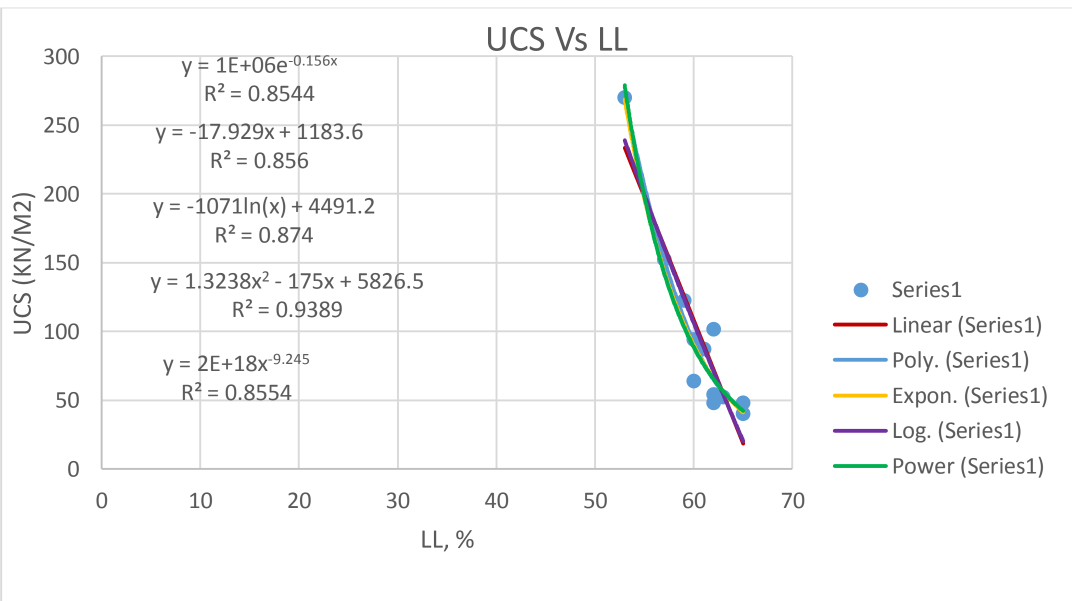

Fig 5.12 Regressing Graph UCS Vs LL, CH soil

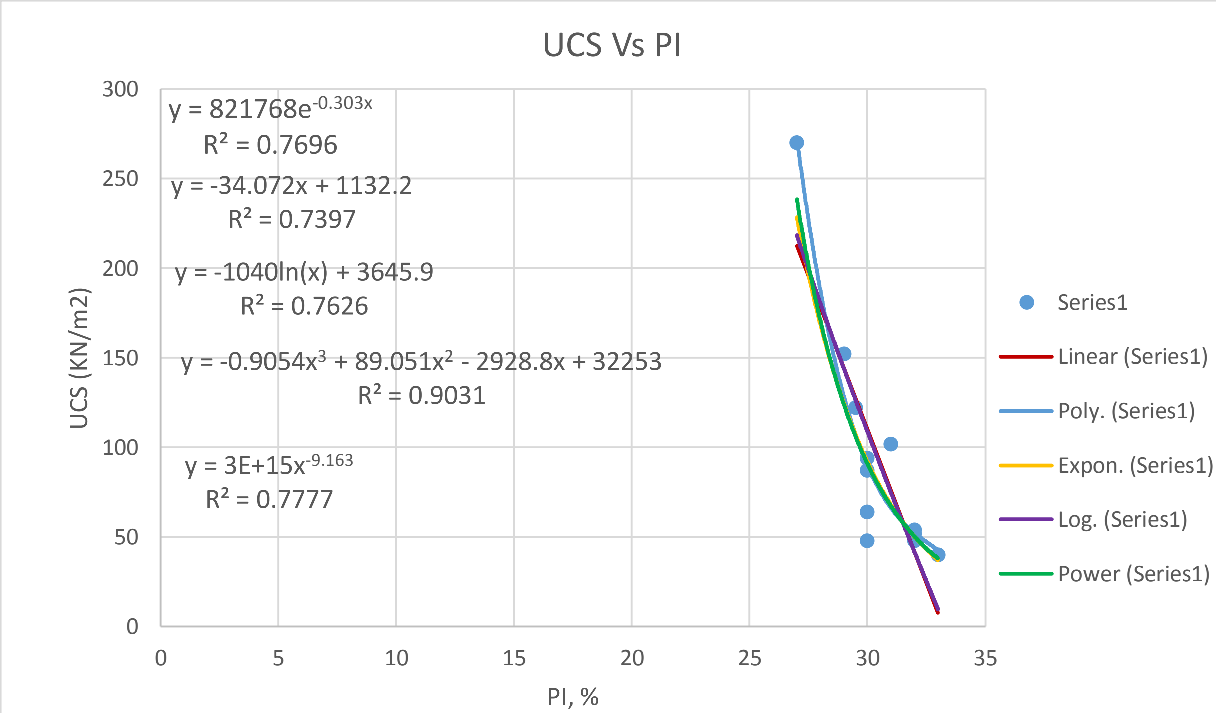

Fig 5.13 Regressing Graph UCS Vs PI, CH soil

The UCS of this soil can be predicted by one of the independent variables P_{200}, LL or PI. All the curves show R^2 value greater than 0.7. The polynomial curve show better relation for three of the independent variables. For the relation with P_{200}, polynomial of 6th order showed value of 0.9763 coefficient of determination. For the relation with LL, polynomial of 2nd order showed value of 0.9389 coefficient of determination. For the relation with PI, polynomial of 3rd order showed value of 0.9031 coefficient of determination. Though these mathematical models seem to show better relation their practicality is poor. From these facts the unconfined compressive strength (UCS) can be better predicted by the model that uses Particles passing 200 sieve as an independent variable by making use of exponential equation with R^2 of 0.8846.

5.2.4.6 Others (CL, GM, SC, CL – ML, & SC – SM)

These soil types rarely found in the study area. They are seen in few bore holes and test pits. Low plastic clay (CL) seen in 3 SBHs', gravely silt (GM) in 2 SBHs'; sandy clay (SC) in 1 STP; low plastic clay-low plastic silt (CL-ML) in 3 SBHs and sandy clay – sandy silt (SC-SM) in 3 SBHs.

5.2.5 Soil cross section profile

Geological cross sections are graphical representations of vertical slices through the earth used to clarify or interpret geological relationship. There are two major classes of cross sections.

Structural cross sections:-which show the present day geometry of an area.

Stratigraphic cross sections: - which show prior geometric relationships by adjusting the elevation of geological units to some chosen geological horizon.

Soil cross sections have been taken by connecting SBH's, STP's and PTP's across the research area. Total of five section taken. These sections are selected in a way that could help see the variation of soil layers and thickness against topography and drainage.

The section considered are

1. section 1-1 STP-10, SBH-64/37 ,SBH-64/62, SBH-25 , STP-1
2. section 2-2 SBH-47, SBH-66, SBH-26, SBH- 30
3. section 3-3 SBH-17, SBH-10, SBH-58, SBH-31
4. section 4-4 SBH-41, SBH-61, SBH-49, SBH-16
5. section 5-5 SBH-35, SBH-66, SBH-13

The section show that upper most layer of the study area is black cotton soil with minimum depth 0.60m around SBH-66 and maximum depth 6.8m around SBH-58.

Second layer, Silty clay/clay silt layer is seen along sections 1-1, 2-2, 4-4 and 5-5. Its existence is from 1.3 to 15m @ SBH-25, from 5 to 11m @ SBH-66, from 1.2 to 9m @ SBH-26, from 3.6 to 10m @ SBH-41, 3.9 to 13m @SBH61, 1.3 to 6m @ SBH-13 and 0.6 to 3.25m @ SBH-35. This layer in some circumstances is overlain by weathered ignimbrite rock as could be seen in the section along section 2-2.

The third layer below the silt clay/clayey silt layer is sandy silt/Silty sand which is witnessed from 16 to 20m @ SBH-47 along section 2-2, 2 to 10m and 18 to 20m separated by weathered ignimbrite rock @ SBH-17, 1.65 to 7m and 11.42 to 20m separated by weathered ignimbrite rock @ SBH-10, 12 to 20m @ SBH-58 and 6to 15m @ SBH31 along section 3-3; from 5.4 to 15@ SBH-49, 1.4 to 7.3m and 19 to 20m separated by weathered ignimbrite rock @ SBH-16 along section 4-4. This layer exists below and in some instances separated by weathered ignimbrite rock.

Forth layer is Sandy gravel. This layer is found around SBH-66 from 11 to 15m along sections 2-2 and 5-5.

The fifth layer is Clayey sandy silt layer which is witnessed along section 5-5. It exists at depths of 3.25 to 10m @SBH-35, 5 to 11m @ SBH-66 and 6 to 13m @ SBH 13. This layer is found below Silty clay layer and above Silty sand layer. In some circumstances it is sandwiched between weathered ignimbrite rocks.

The other layer witnessed in the sections is weathered ignimbrite rock. It is found at variable depths ranges. Along section 2-2 from 1.3 to 16m @ SBH-47, 0.6 to 5m @ SBH-66 and it is found below black cotton soil and above Silty clay/Clayey sandy silt layers. Along section 3-3 from 10 to 18m @ SBH-17, 7 to

11.42m @ SBH-10, 6.8 to 12m @ SBH-58 and it is sandwiched between sandy silt layers and below black cotton soil layers. Along section 4-4 from 0.4 to 3.9m @ SBH-61, 4 to 5.4m @ SBH-49, 7.3 to 19m @ SBH-16 and it is found below black cotton soil and above sandy silt and Silty clay layers. Along section 5-5 from 0.6 to 5m @ SBH-66, 13 to 20m @ SBH-13 and it is found below black cotton soil and clayey sandy silt soil layers.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

Based on the secondary and primary data of this research the following conclusion are drawn:

- There are four major soil types in the study area. These soil types are MH, ML, SM and CH in their order of dominance.
- MH soil has percent fines of range 54 to 99.6% and average 85.04% fines, liquid limit range 50 to 116% and average 78.62%, plastic limit range 24 to 84% and average 43.25%, plasticity index range 7 to 66% and average 35.39% and moisture content range 5.65 to 67.37% and average 37.42%, specific gravity range 2.03 to 2.84 average 2.53 and free swell range non swelling to 200% and average 84.25% .Based on the result averages the soil was in the solid state and it is also marginally expansive soil.
- MH soil has also UCS range 25.94 to 206 KN/m2 and average 95.69KN/m2 showing that the soil was in consistency state of firm.
- MH soil UCS can be better predicted by relation with LL with exponential equations, $y = 14.692e^{0.0217x}$ with R^2 values of 0.5449. No adequate relation found between UCS and P200/ PI.
- ML soil has percent fines of range 51.9 to 93.3% and average 69.6% fines, liquid limit range 0 to 65% and average 26%, plastic limit range 0 to 37% and average 17.5%, plasticity index range 0 to 32.69% and average 8.6% and moisture content range 12.08 to 48.17% and average 27.1%, specific gravity range 2.48 to 2.68 average 2.6 and free swell range non swelling to 145% and average 23.5%. Based on the result averages the soil was non expansive soil.
- ML soil has also UCS range 34.04 to 200 KN/m2 and average 80.7KN/m2.
- SM soil has percent fines of range 11.8 to 47% and average 32.6% fines, liquid limit range non plastic to 71% and average 27%, plastic limit range non plastic to 60% and average 20.6%, plasticity index range non plastic to 31% and average 6.4% and moisture content range 11.04 to 51.71% and average 28.3%, specific gravity range 2.16 to 2.8 average 2.6 and free swell range non swelling to 70% and average 18.2% .Based on the result averages this soil type non expansive soil.
- SM soil has also UCS range 40.7 to 285 KN/m2 and average 137.1KN/m2.
- CH soil has percent fines of range 50.98 to 99% and average 79.45% fines, liquid limit range 53 to 113% and average 68.52%, plastic limit range 16 to 42% and average 30.95%, plasticity index range 24 to 73% and average 37.73% and moisture content range 24.82 to 51.49% and average 36.2%, specific gravity range 2.63 to 2.67 average 2.65 and free swell range 10 to 130% and

average 90.45% .Based on the result averages the soil was in the plastic state and it is also marginally expansive soil.

- CH soil has also UCS range 40 to 270KN/m2 and average 94.45KN/m2 showing that the soil was in consistency state of firm.
- The UCS of CH soil can be better predicted by one of the relation with P_{200}, LL or PI by making use of the curves of exponential and linear. The curves show R^2 values greater than 0.7.i.e exponential in their order of list are $y = 9.1527e^{0.0315x}$, $y = 1E+06e^{-0.156x}$, $y = 821768e^{-0.303x}$ with R2 0.8844, 0.8544, 0.7696 and Linear equation $y = 3.3608x - 137.19$, $y = -17.929x + 1183.6$ and $y = -34.072x + 1132.2$ with R^2 0.7681, 0.856, 0.7397.
- The soil in the study area can be compacted to maximum dry density range of 1.67 to 1.7 g/cm3 at optimum moisture content range of 18.5 to 23.4 %.
- The permeability coefficient (K_{20}) range of soil in the study area fall from 2.8 to 5 (x 10^{-3}) cm/sec.
- In the study area soil layers of black cotton (Silty clay/clayey silt) soil layer, Silty clay/clayey silt soil layer, Sandy silt/Silty sand layer, sandy gravel layer and weathered ignimbrite layers existed.
- The soil of the study area is very erratic both spatially and along depth.

6.2 RECOMMENDATION

- In areas where thick layer of (black cotton) expansive soils exist great care has to be taken while placing foundation. Replacing of the soil with appropriate granular soil brought from other sites, reclaiming the soil with lime or saturating the soil prior to construction need to be done.
- The research is based on limited secondary and primary data both in amount and spacial distribution. Therefore it will be best if further research could be carried in a more size of data both in terms of amount and distribution.
- In this research only dry sieve analysis is carried and in future works wet sieve could be incorporated.
- Chemical tests of minerals of soils and solutions not carried to relate them with their parent material of formation. So works in these regard could reveal more information on soil of the study area.
- The prediction model for UCS of all types of soils was attempted by making use of P200, LL and PI on mono variable bases and limited data amount. Therefore it would be good if further work could be done on large scale of data and on multi variable bases and also in consideration of other properties like density and moisture content.
- Construction of light weight structures on expansive soil in the area should be done with associated remedial actions.

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Appendix

Appendix A

Appendix B

Appendix C

Appendix D